

Technical Aspects of Acoustical Engineering for the ISS

The 4th Meeting of the MidSouth Chapter of the Acoustical Society of America

The University of Central Arkansas
Conway, AR 72034

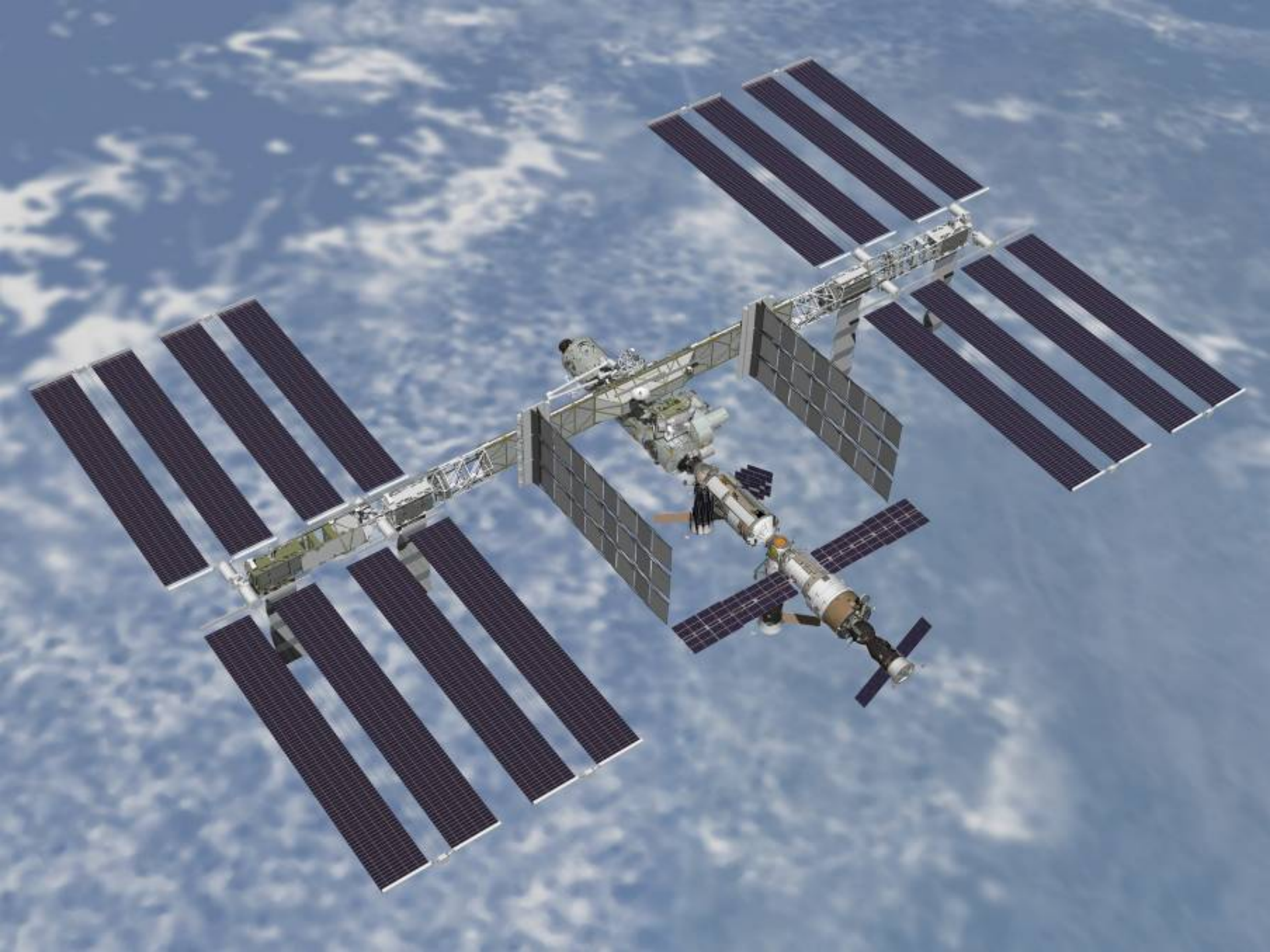
March 6-7, 2009

Chris Allen /JSC Acoustics Office/SF22

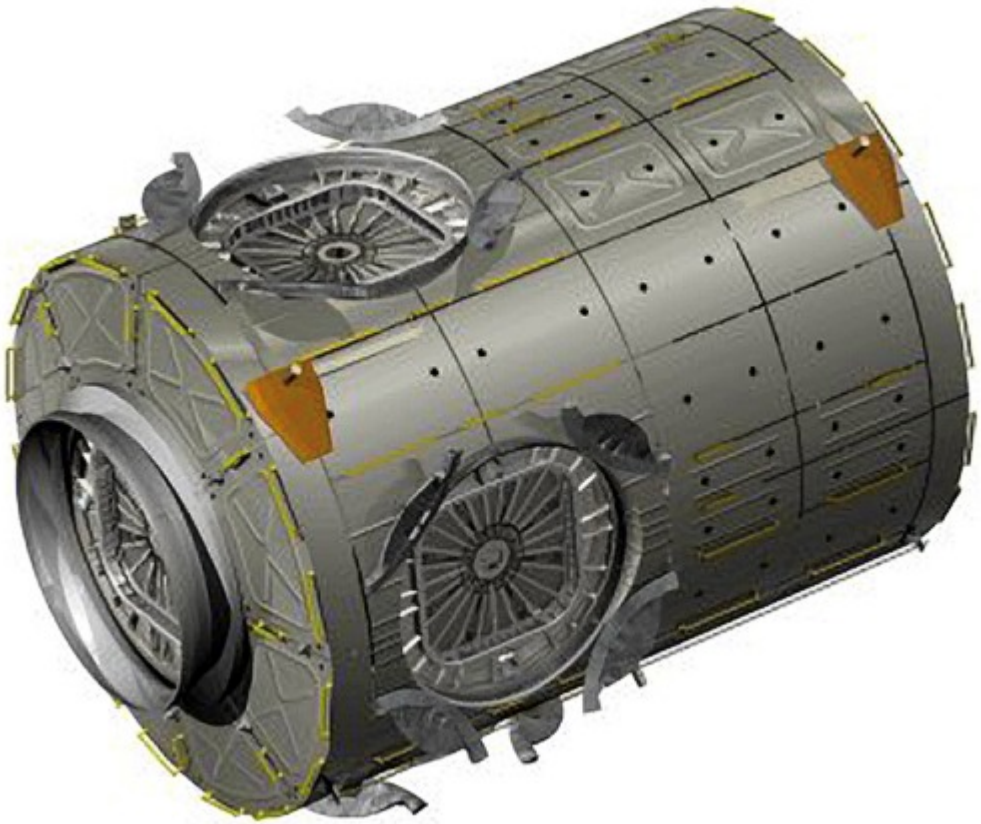
Outline

- *ISS Overview*
- *Controlling Acoustical Noise*
- *Examples*
  - *Service Module*
  - *US Segment Ventilation*
  - *Crew Quarters*





Nodes 1, 2, and 3



S P

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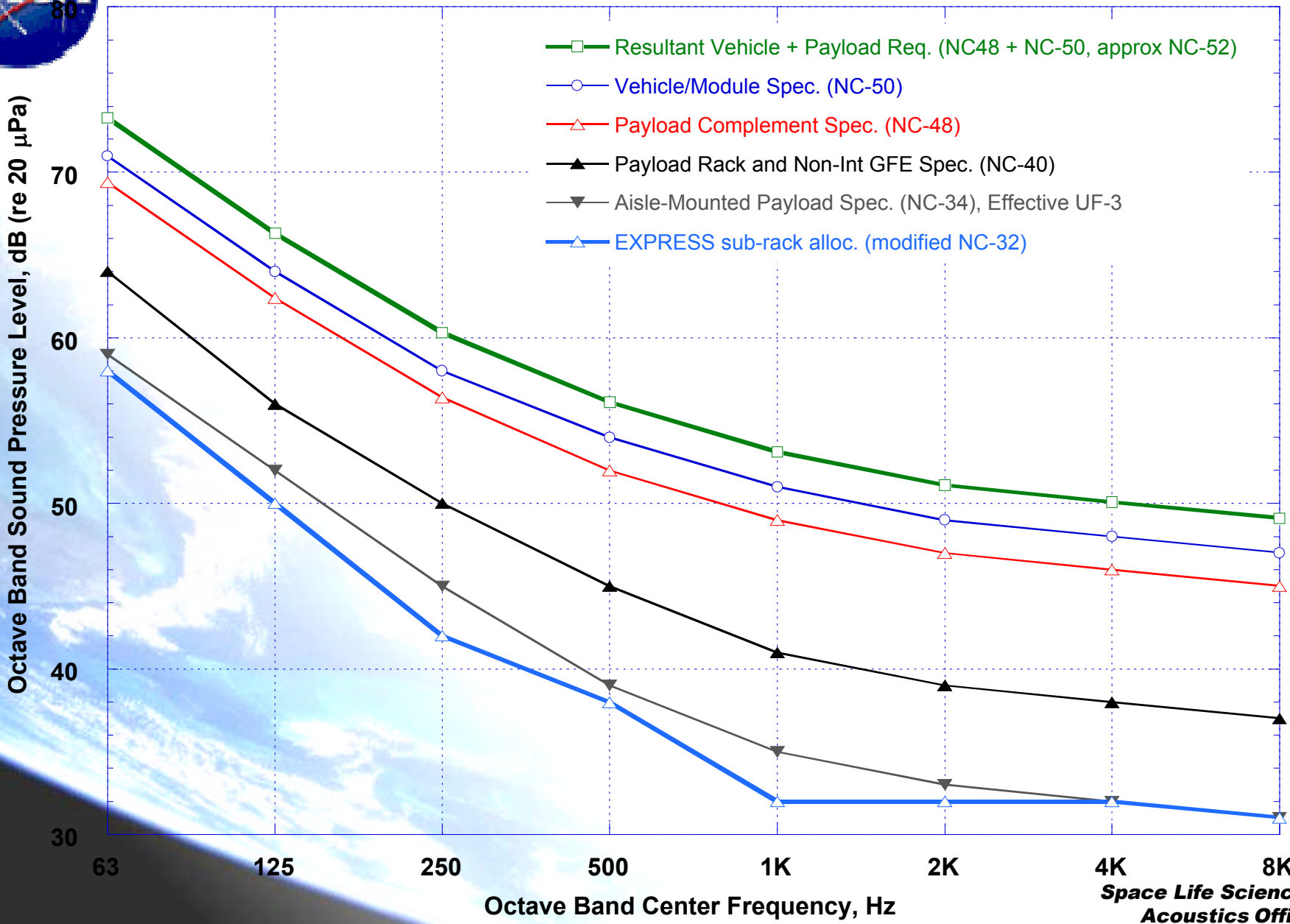
What Makes Noise on ISS?

- Hardware
- Air conditioning, fans, water cooling pumps, refrigerators, experiments, exercise equipment, computers, cameras, hundreds of pieces of equipment (vacuum cleaner, hair trimmer)
- Modules are reverberant (T_{60} approx. 0.5s)

Controlling Acoustical Noise

- Sound levels in space vehicles must be controlled
  - Hearing conservation
  - Protect communications
  - Alarms audibility
  - Habitability
- Requirements and verification requirements
  - Allocated requirement depending on system level
- Hardware design and reviews (SRR, PDR, CDR)
  - Acoustic Noise Control Plan (ANCP)
- System-level analysis
- Remedial actions and noise control
- Certification of Flight Readiness (CoFR)
- On-orbit acoustical monitoring

Continuous Noise Requirements



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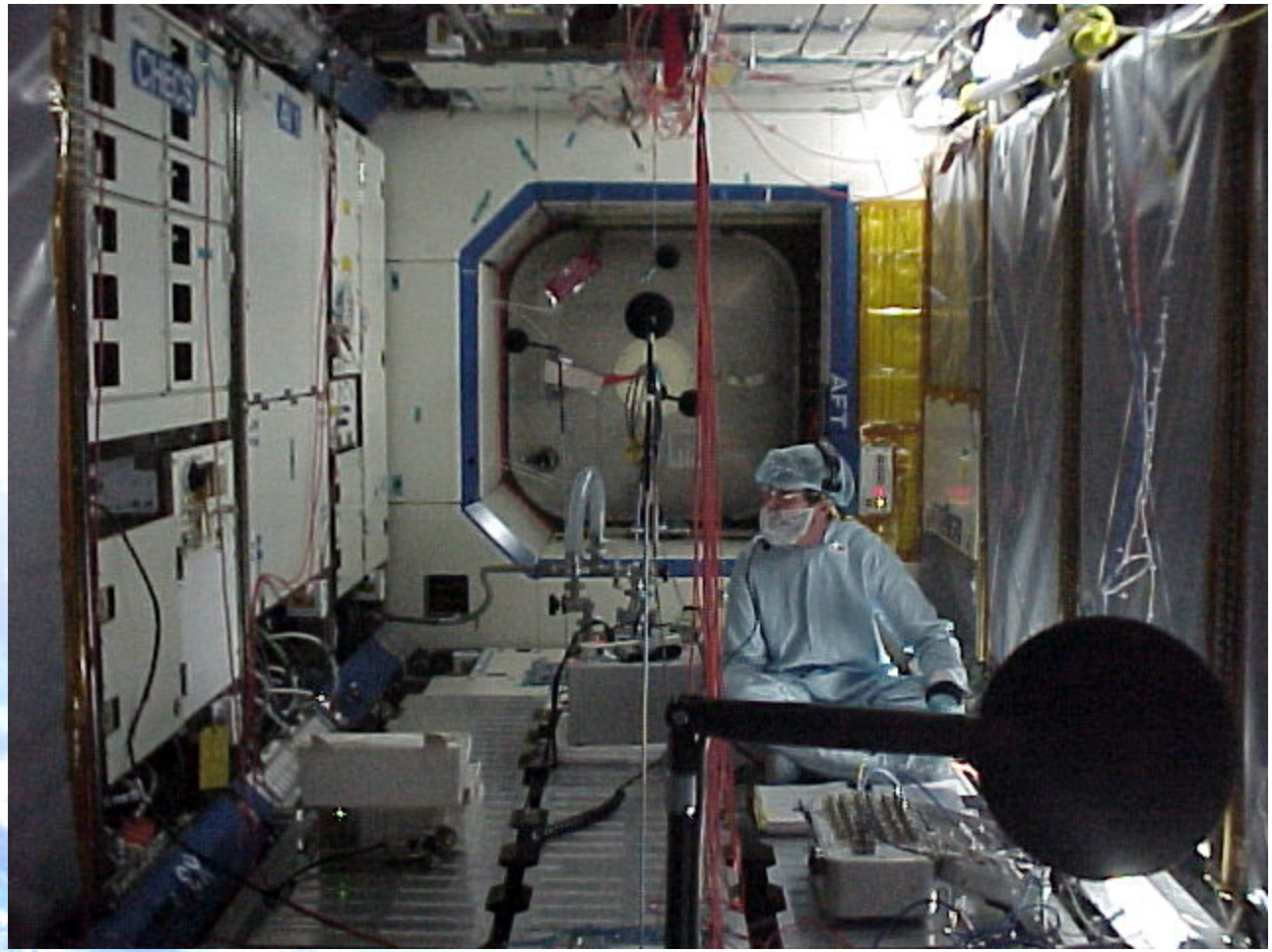
Acoustic Noise Control Plan

- Indicate allocation and integrator
- Sub-allocations for components
  - Identify noise makers
  - Select quiet components
  - Design in noise controls – isolators, absorption
- Operational Scenarios
- Account for changes throughout lifetime of h/w
  - Rack with changing sub-rack payloads
  - Orbital Replacement Units (ORUs)
- Documentation
  - Specify limits and verification requirements for components
  - Specify limits, verification requirements and process for ORUs
- Testing and Verification Plan
  - Determine insertion losses and other transfer functions
  - Test-correlated analytical model
- Recovery Plan

Verification

- **Test**
  - **Preferred method**
  - **Most hardware**
  - **Worst-case nominal operating conditions**
- **Test-correlated analytical model**
  - **Used for payload rack facilities which are designed to support multiple experiments**
  - **Experiment hardware not yet available**
  - **Testing used to determine**
    - Base facility noise
    - Insertion losses/transfer functions
    - Sub-rack payload/experiment noise when available
  - **Model describes how to combine the test data to predict integrated rack noise**
  - **Model documented in Acoustic Noise Control Plan (ANCP)**
  - **Worst-case nominal operating conditions**

Module Verified by Ground Test

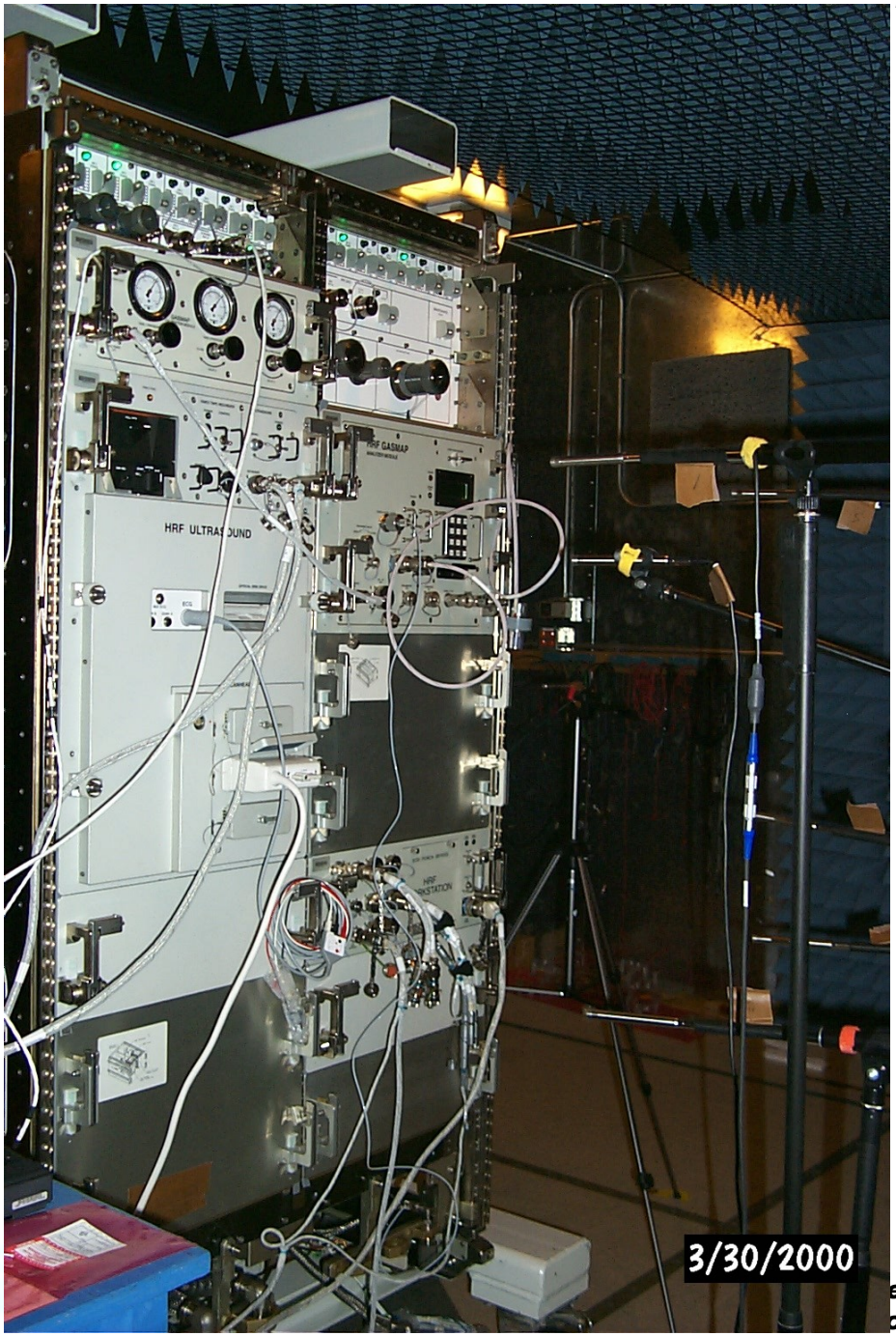


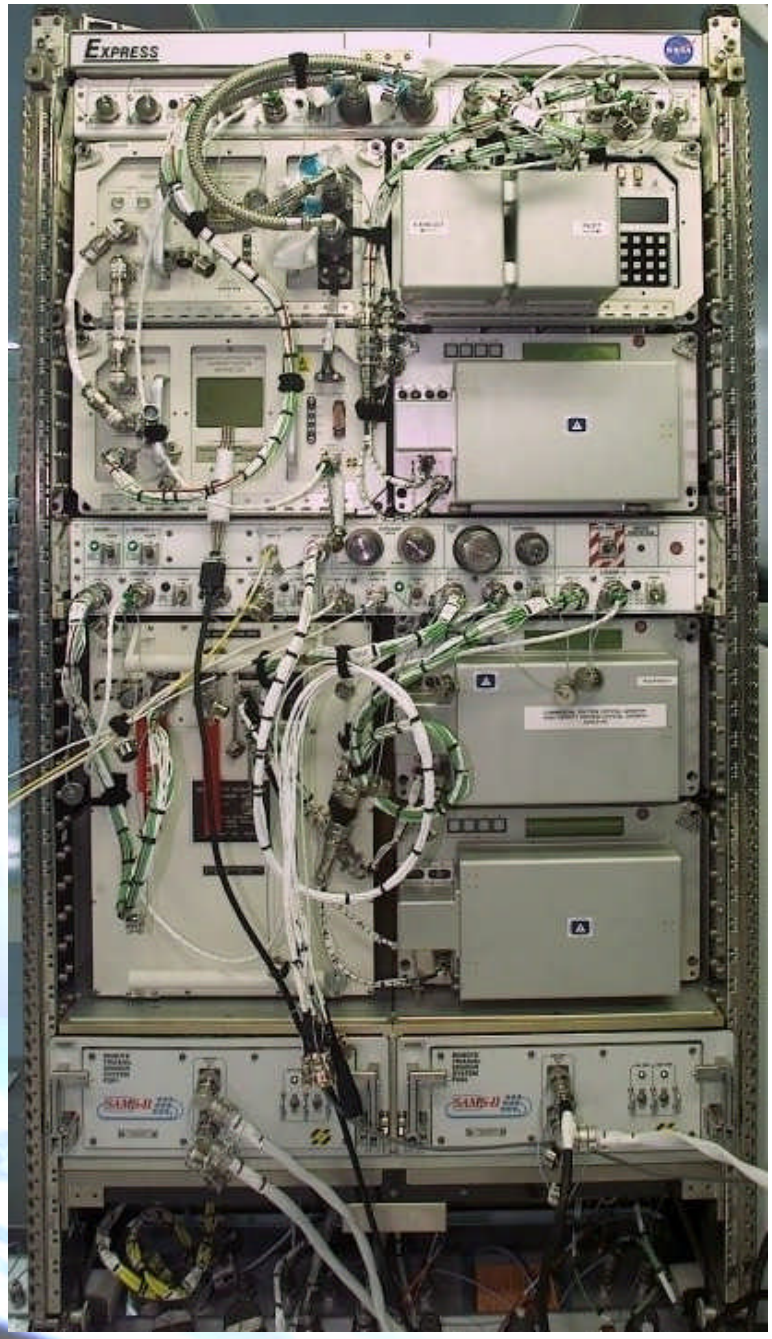
- *Includes Integrated GFE*
- *Some analysis may be used under certain circumstances*

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Integrated Rack Verification

- Two feet from Rack
  - All sides of rack
  - Bottom measurements
- Payloads not changed-out
- Payloads changed out
  - Rack system noise
  - Insertion losses/transfer functions
  - Inputs to model
- All operational scenarios
- Throughout lifetime





ADVASC

MAMS

SAMS-I

CGBA

PCG-STES

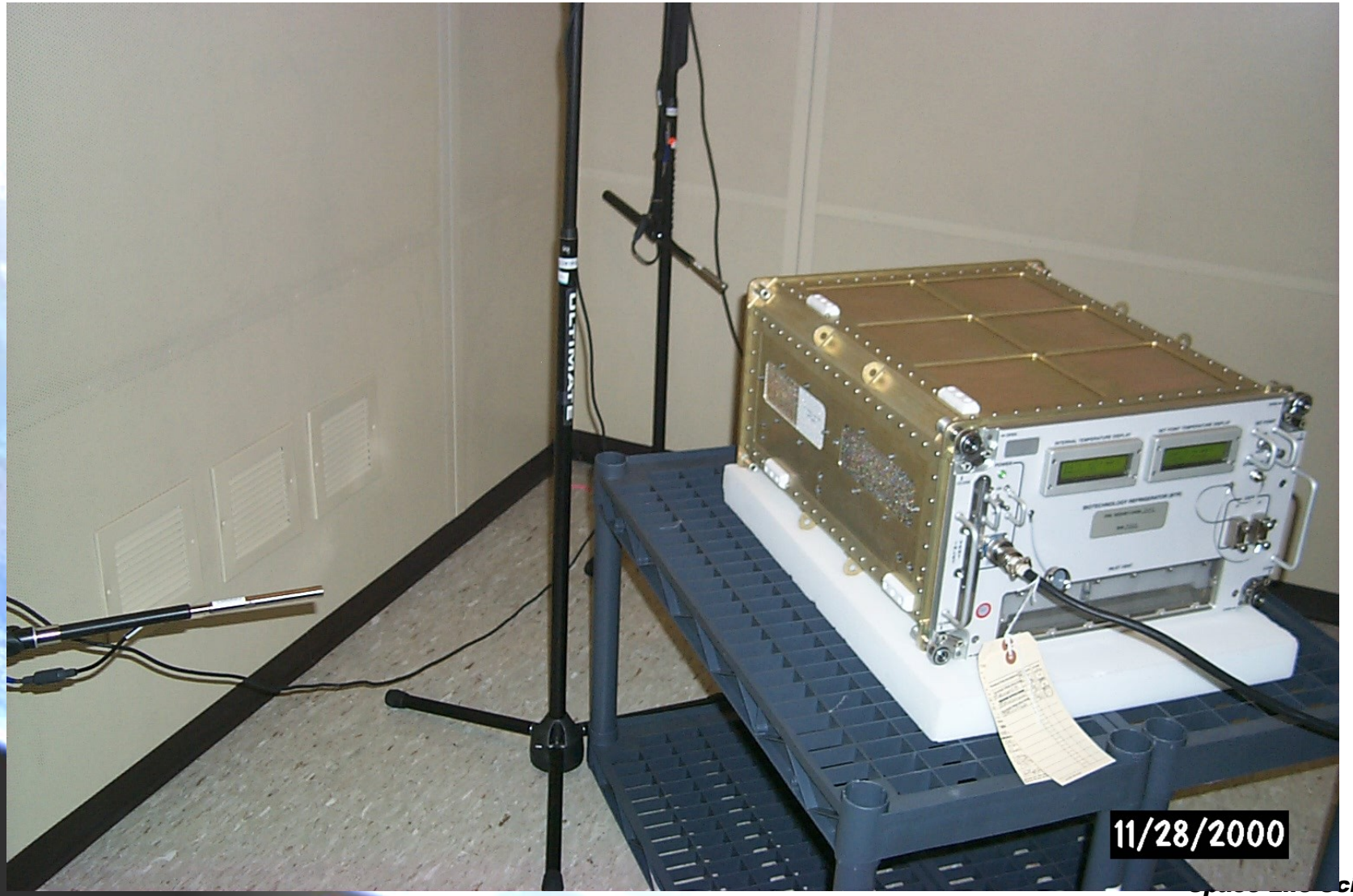
CPCG

PCG-STES

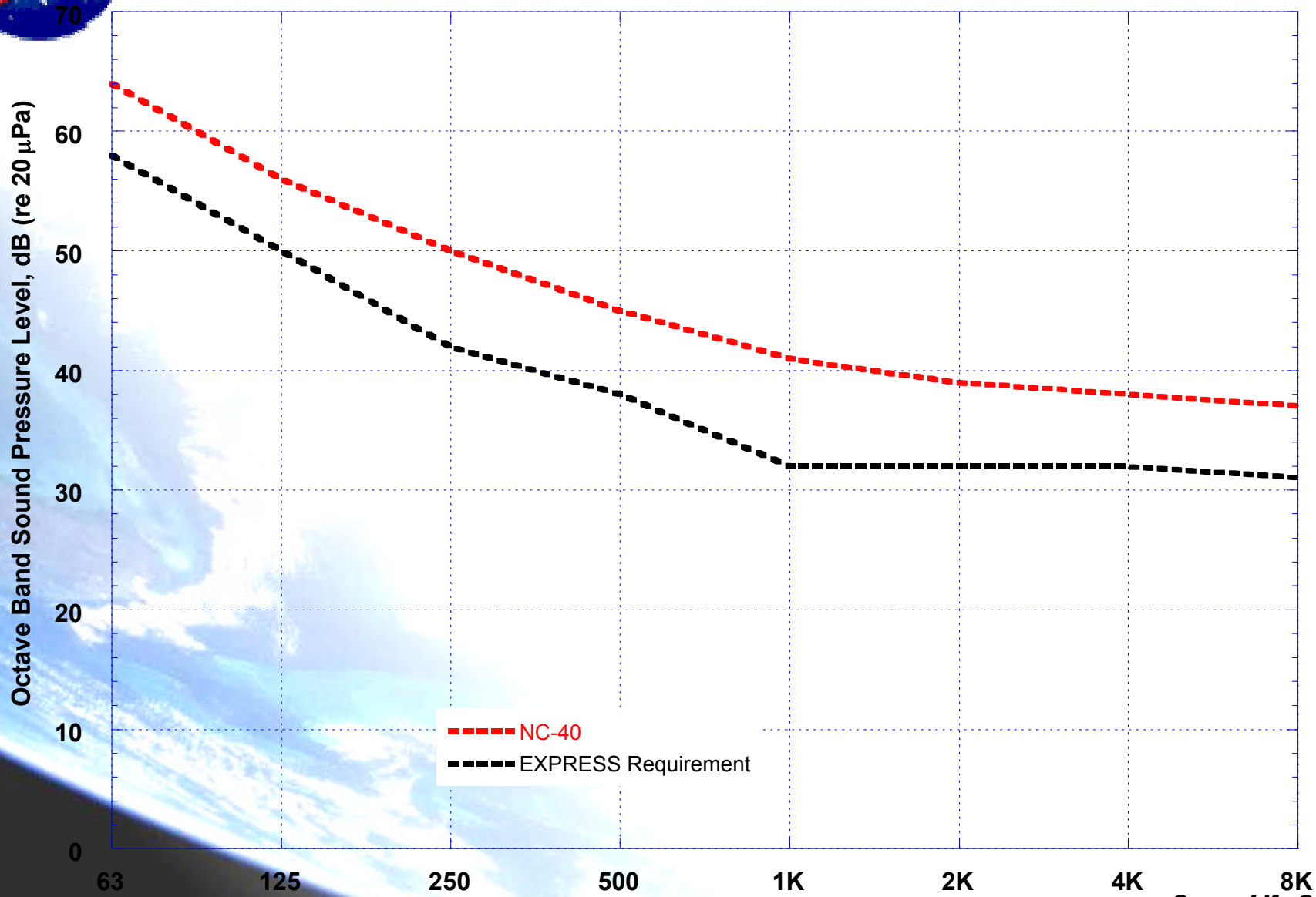
SAMS-II

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Sub-Rack Payload Verification

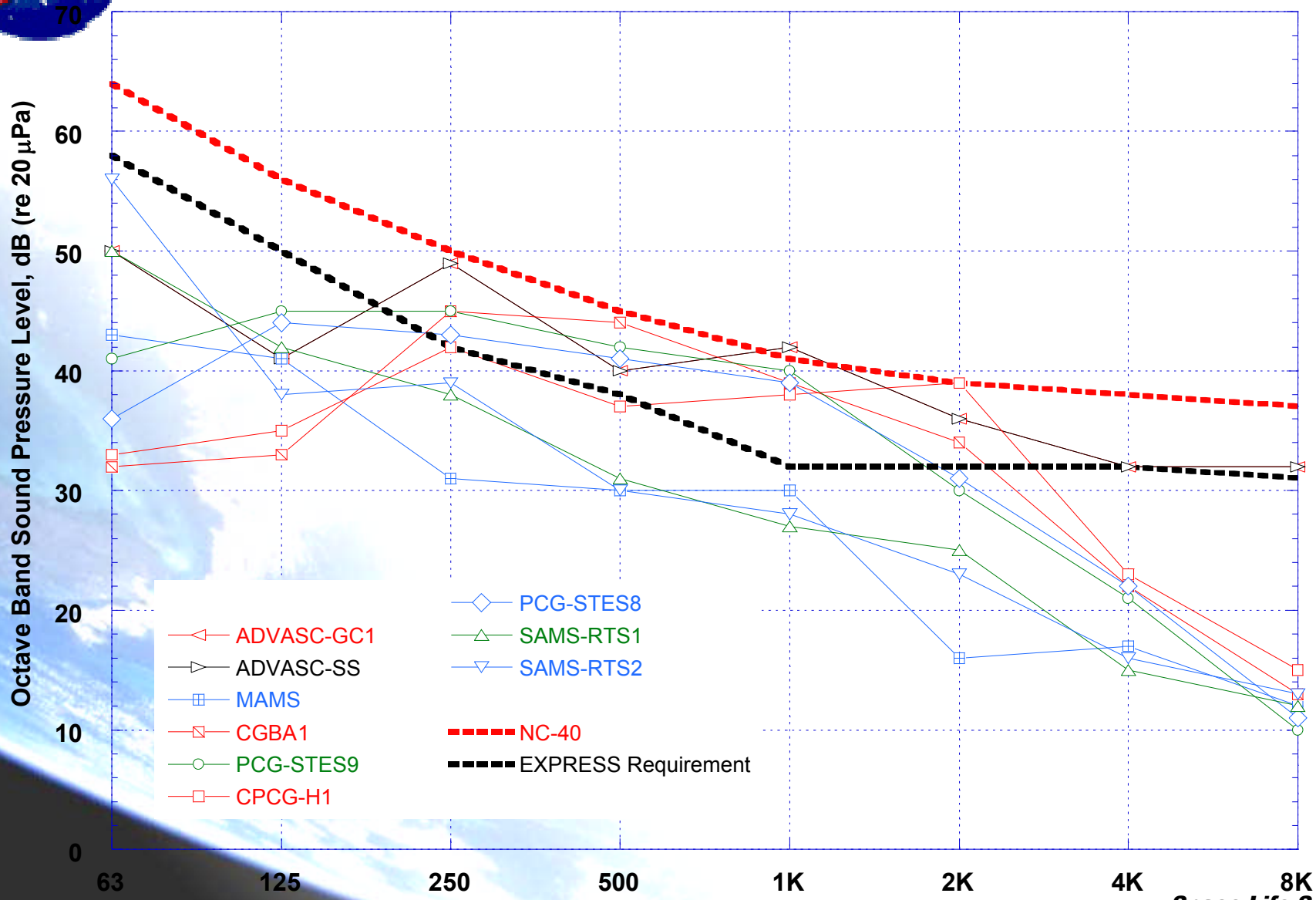


Rack Verification from Model



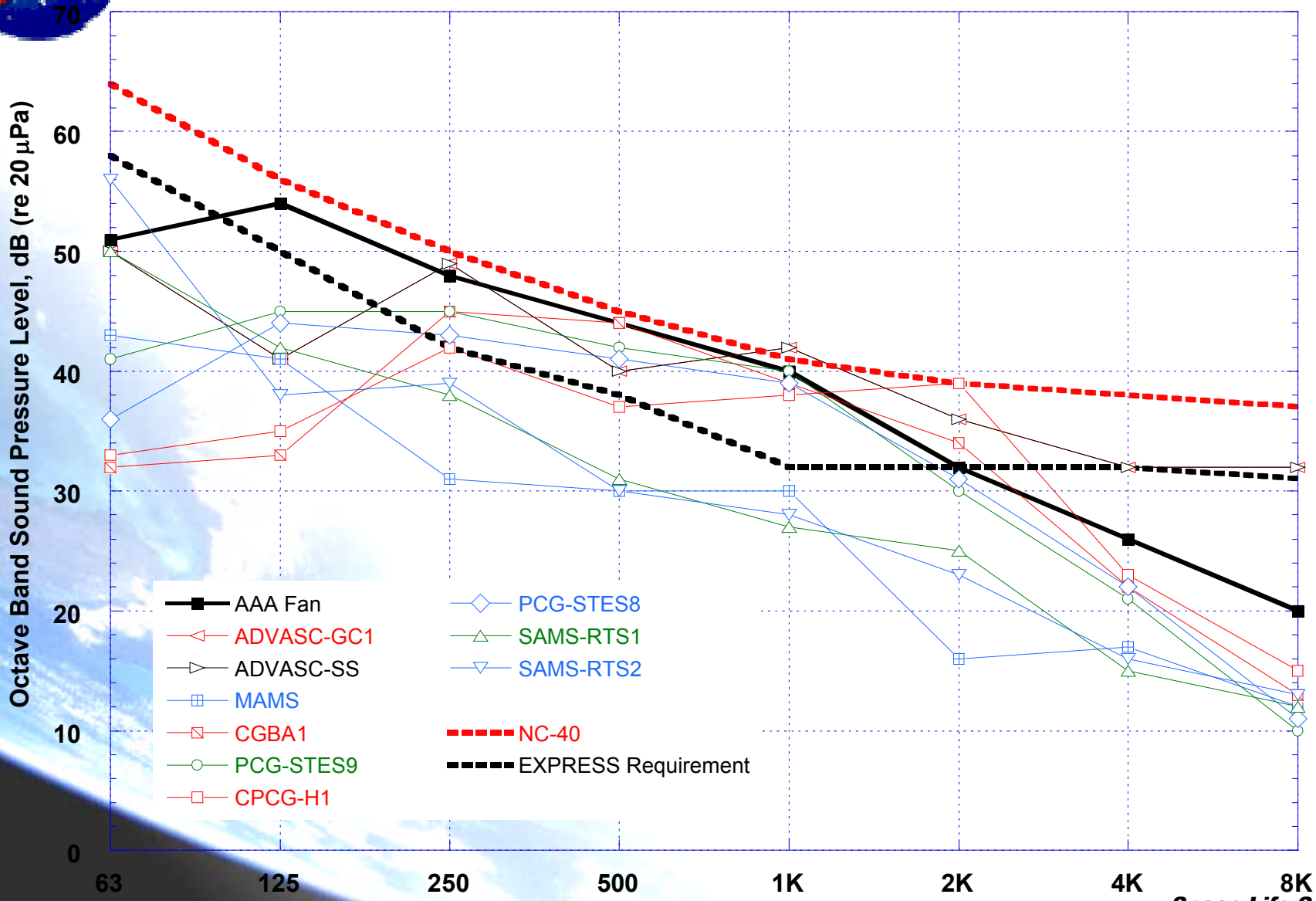
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Rack Verification from Model



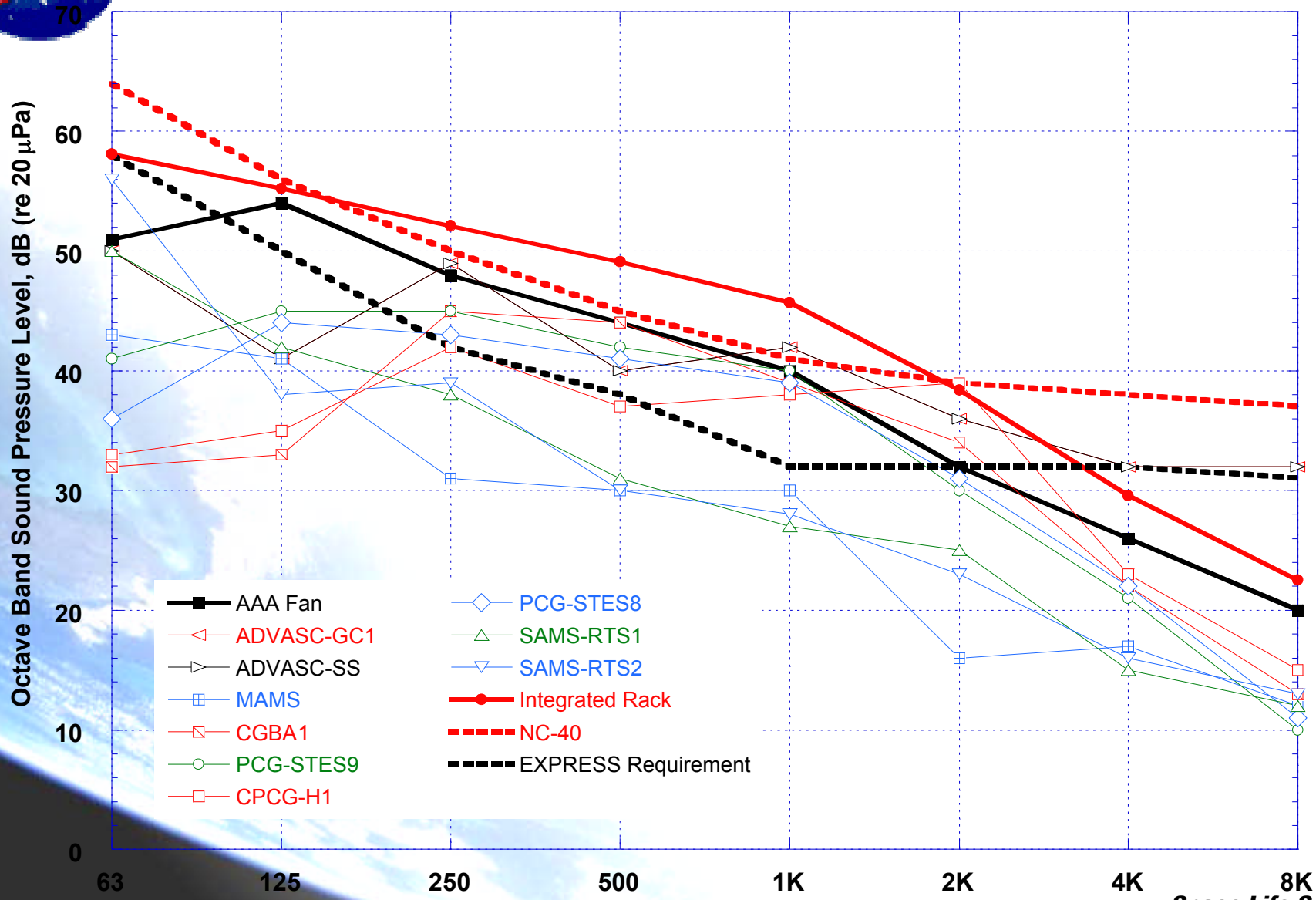
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Rack Verification from Model



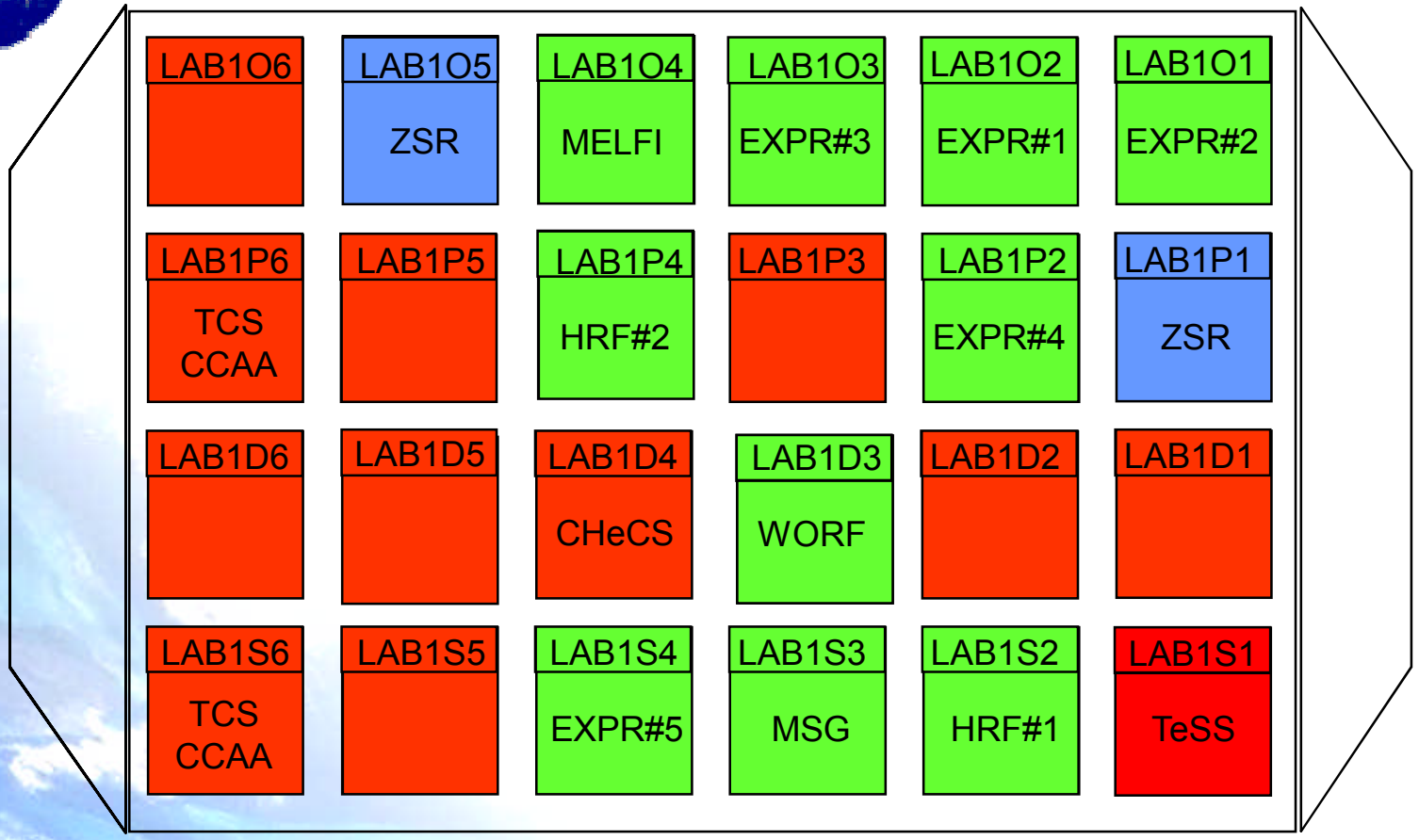
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Rack Verification from Model



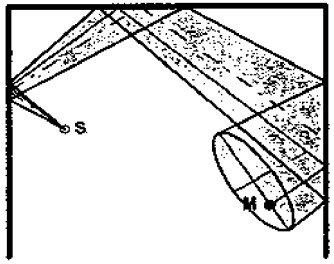
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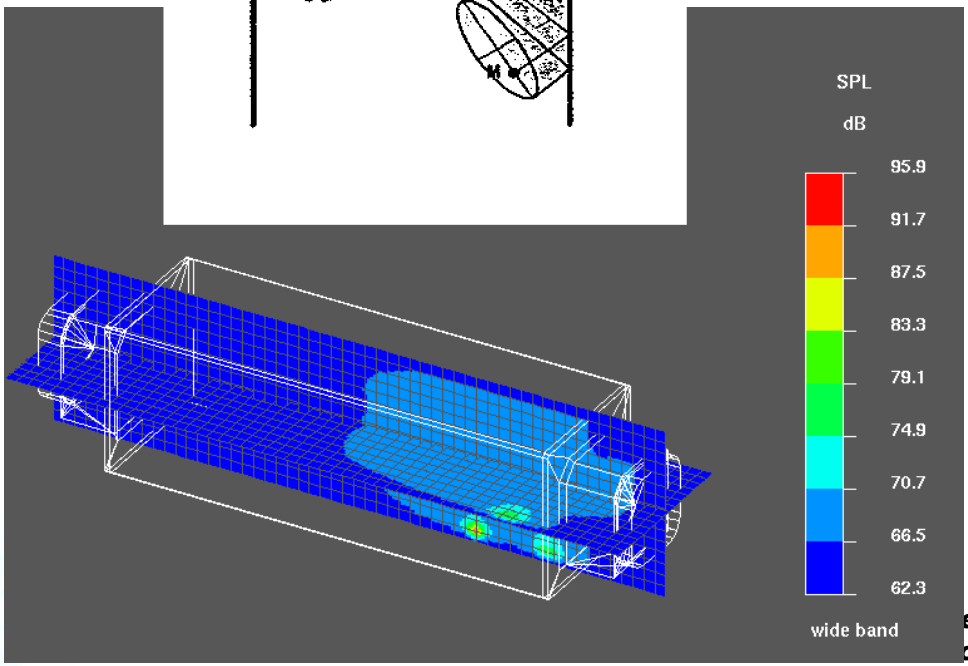
Typical US Lab Topology



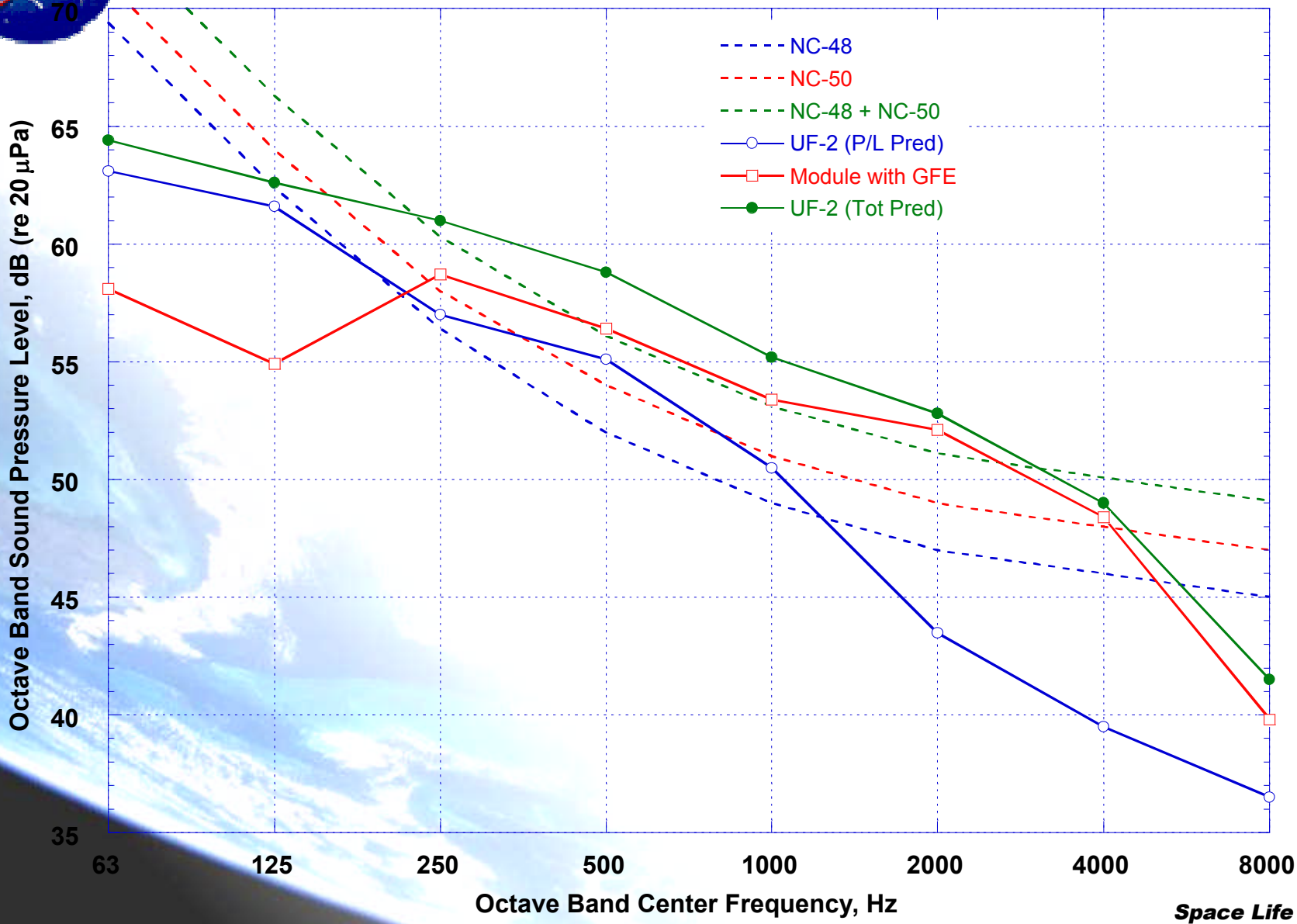
System Level Noise Prediction

- ***RAYNOISE Software***
  - ***based on enhanced geometrical*** *ray-tracing algorithm*
  - ***computes sound levels in any closed or open volume***
  - *sound reflection at a wall is specular****, or can also be diffuse***
  - *sound is partially absorbed at a wall* ***depending on the wall absorption coefficient***
  - ***contribution of many rays at a point determines the sound level***
- ***Inputs***
  - *geometry* ***of acoustic space***
  - ***"receiver surface" geometry***
  - *absorptive properties* ***of room boundaries***
  - *sound power levels* ***and directivity information for*** *noise sources*
- ***Outputs***
  - *Sound Pressure Level* ***on "receiver surface"***



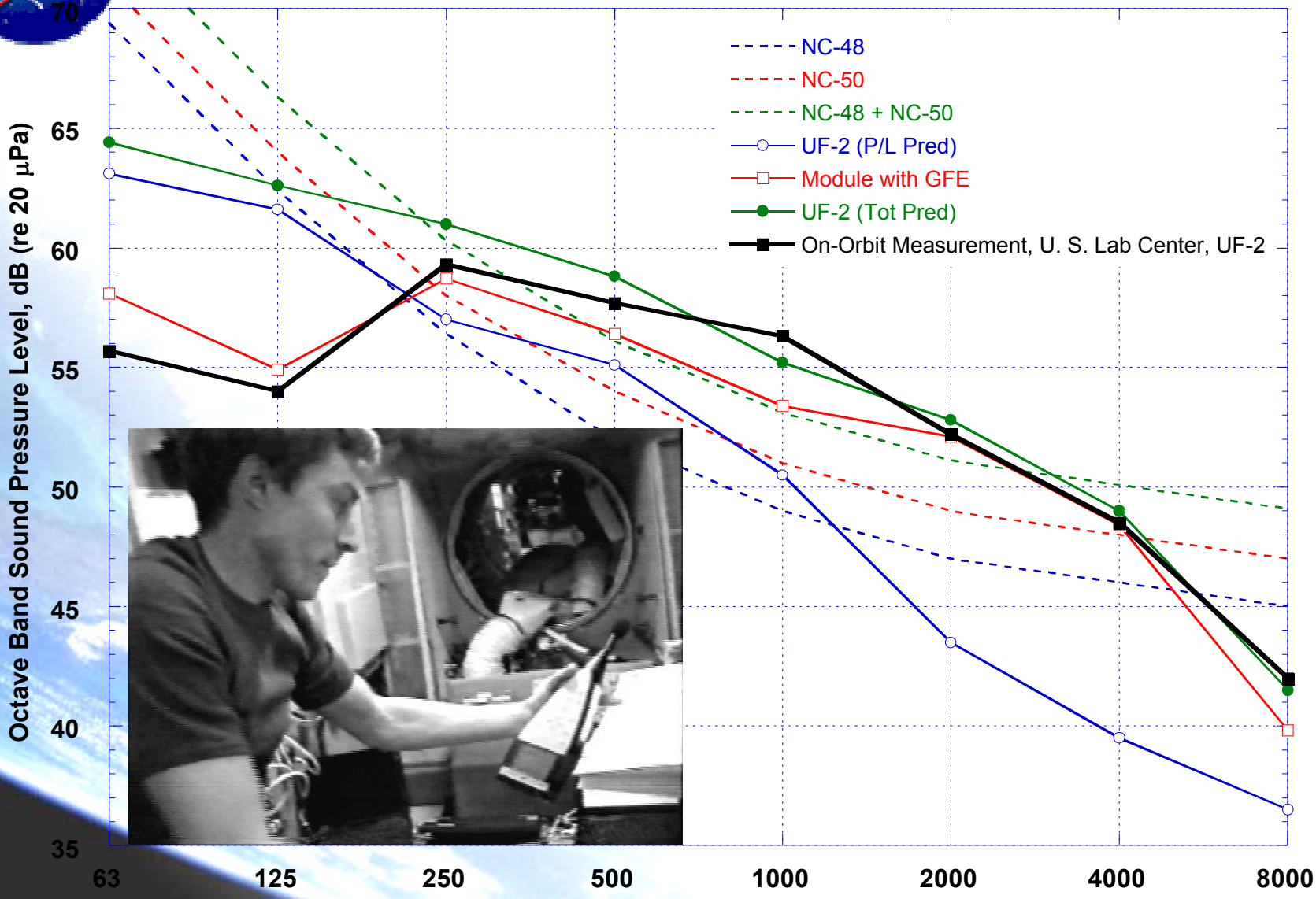


System Level Continuous Noise



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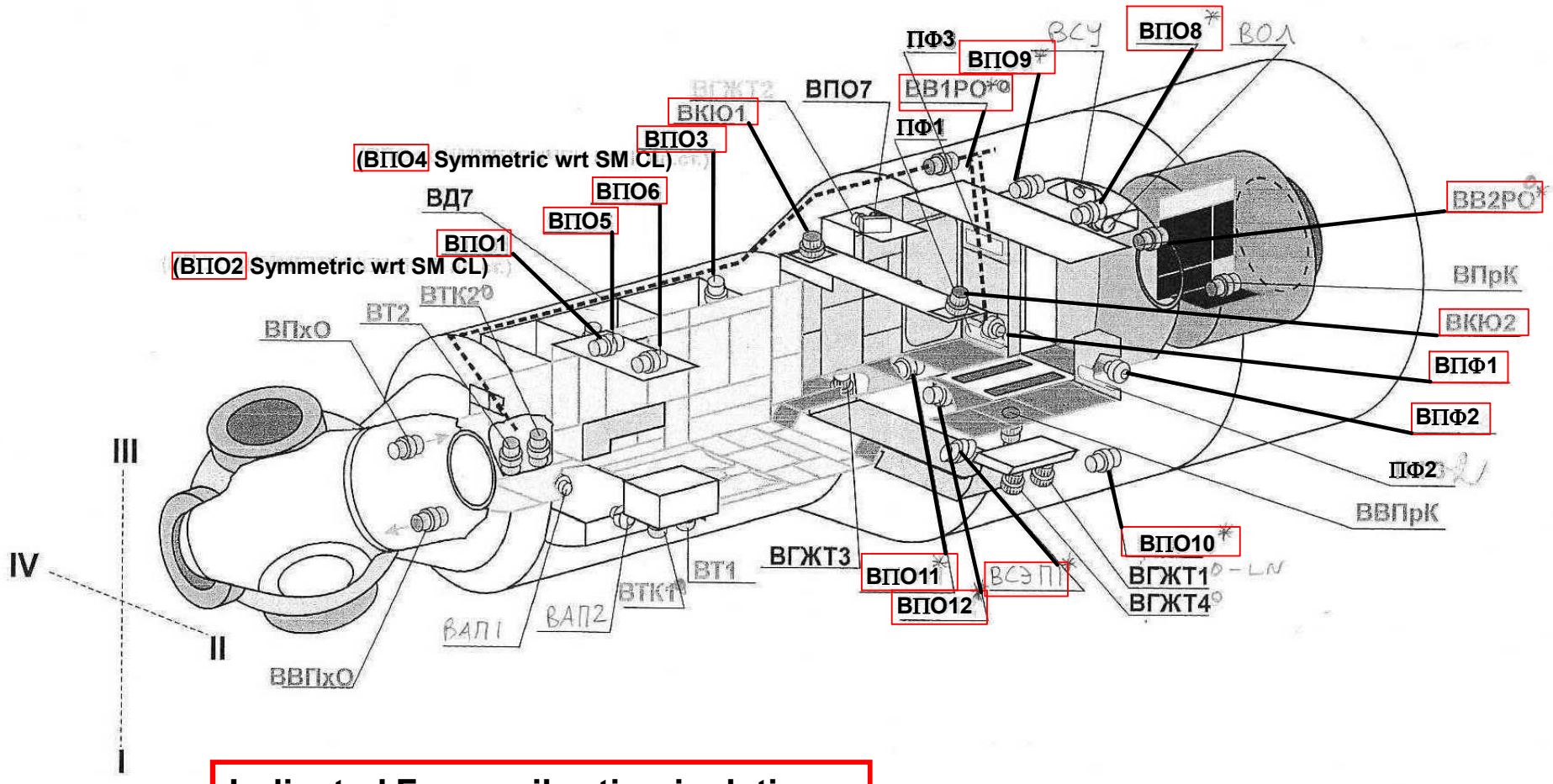
On-Orbit Measurement Comparison



Payload Complement Prediction by Ed O'Keefe
Module Prediction by Sam Denham

Service Module Ventilation Subsystem Noise Control

Service Module Ventilation System Fans



Indicated Fans - vibration isolation
- acoustic lined duct

Ventilation Subsystem

Installation of soundproofing device on ВПО12





Ventilation Subsystem

Installation of soundproofing device on ВПО10, ВПО11, ВСЭП1







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Ventilation Subsystem

Installation of fan ВПФ1 on vibration isolation.
Installation of soundproofing device on ВПФ1 and dust collector



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Ventilation Subsystem

Installation of fans on vibration isolation



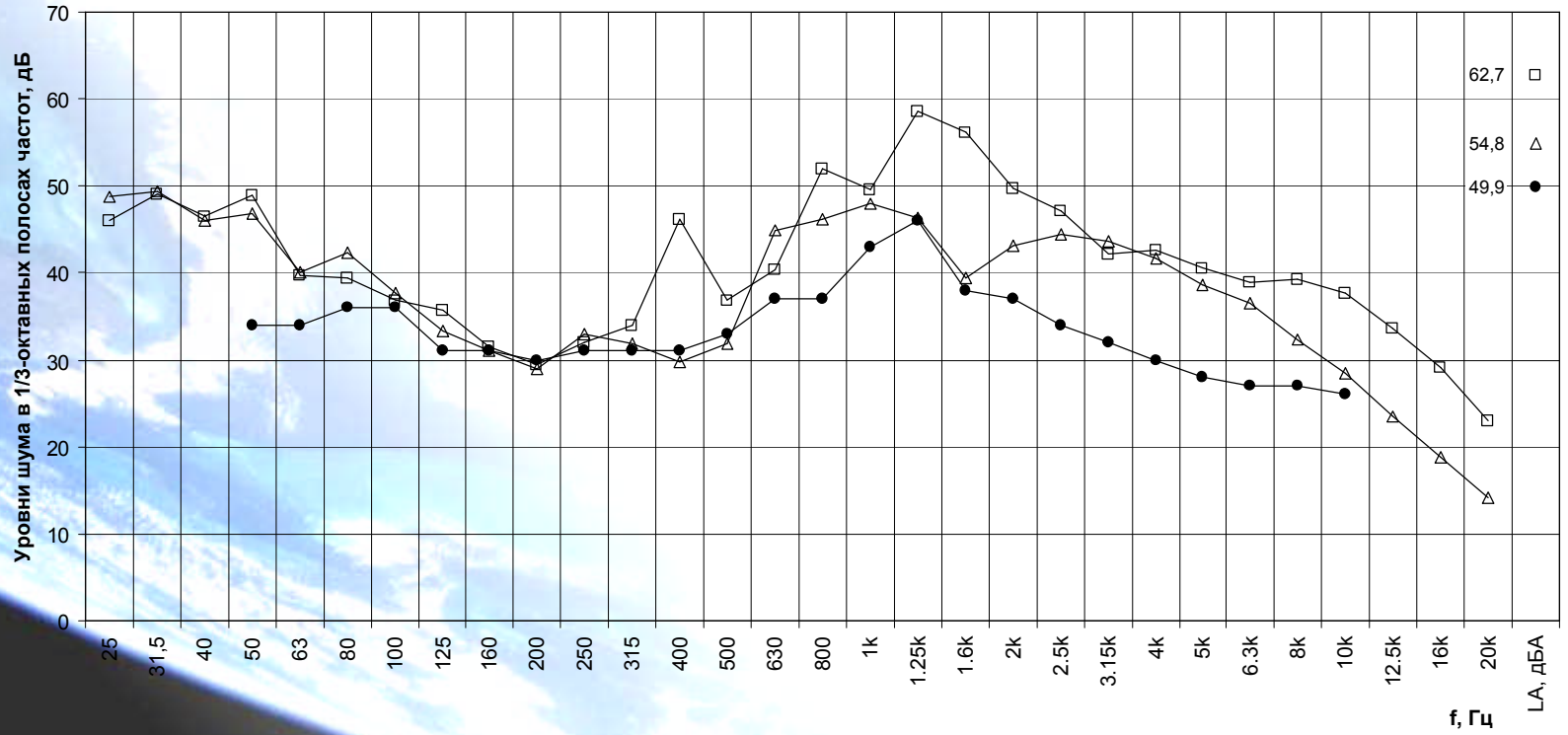
SM Acoustic Contract Status

Quiet Fan Development

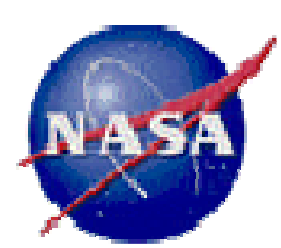








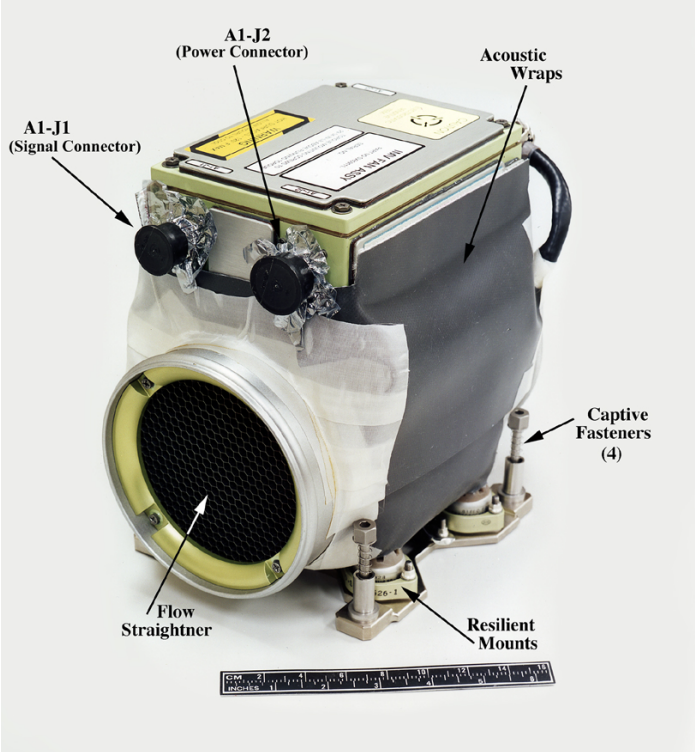
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US Intermodule Ventilation (IMV) Fan

IMV Fans – Case Radiated Noise

- The IMV Fan Assembly consists of a cast aluminum fan housing, a brushless DC motor, an axial flow impeller, flow straightener, a motor controller, vibration isolating resilient mounts, and acoustic insulation.
- Acoustic wraps cover the exterior of the IMV Fan Assembly to attenuate case radiated noise emissions
- Further attenuation of case radiated noise is provided by the aluminum honeycomb closeout panels

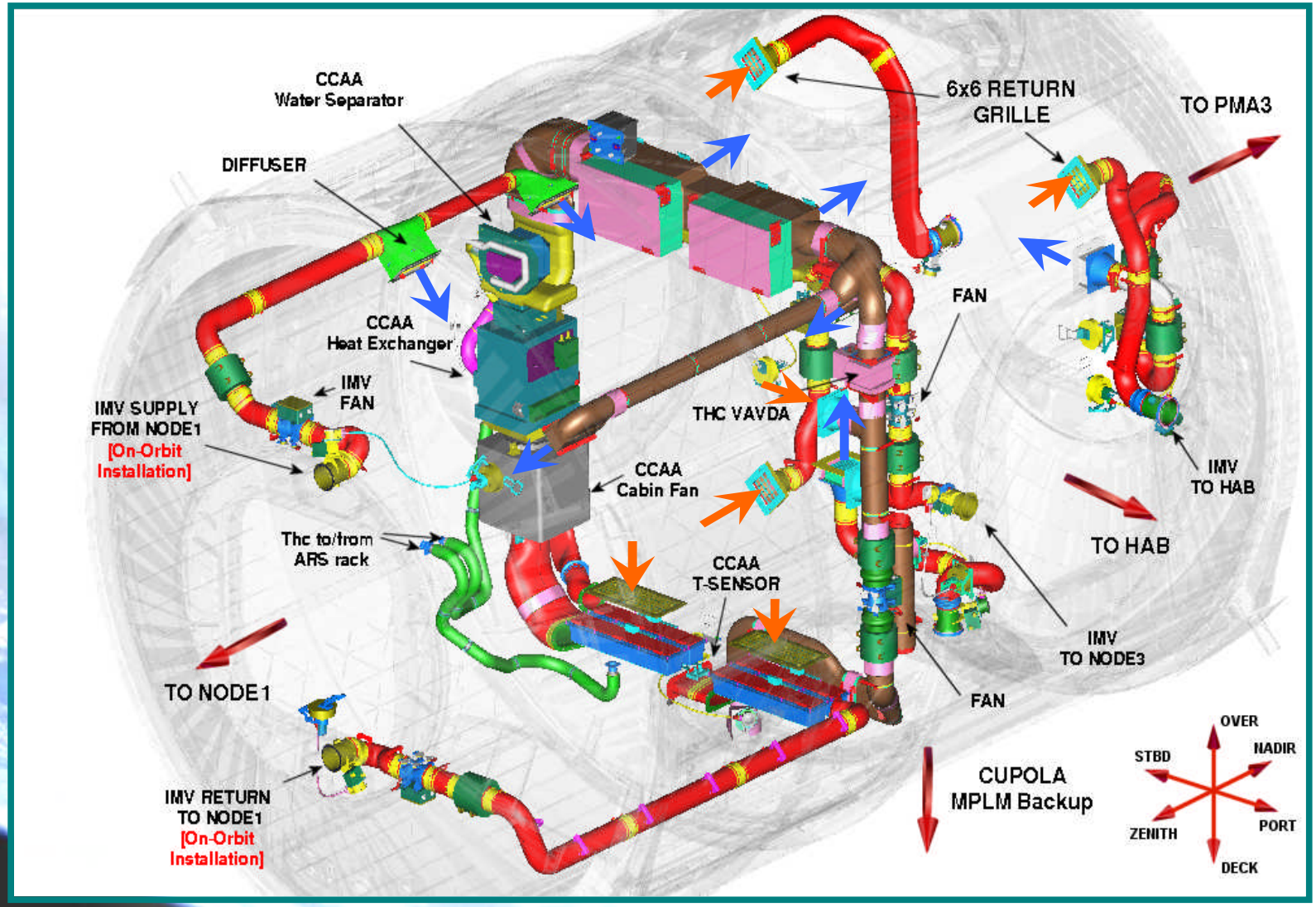


IMV Fans – Ductborne Noise

- ***Treatment - Muffler***
  - IMV muffler the "football" muffler
  - Made of “Feltmetal” and Melamine foam

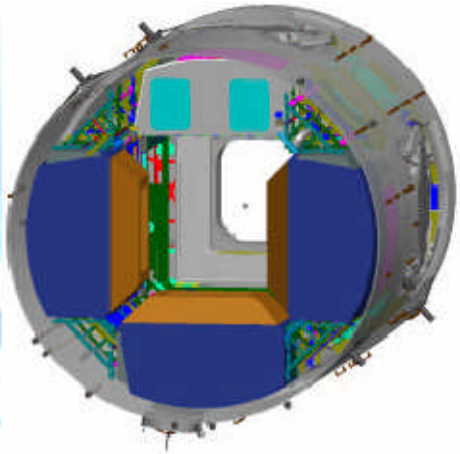


Node 3 Ventilation System



Crew Quarters

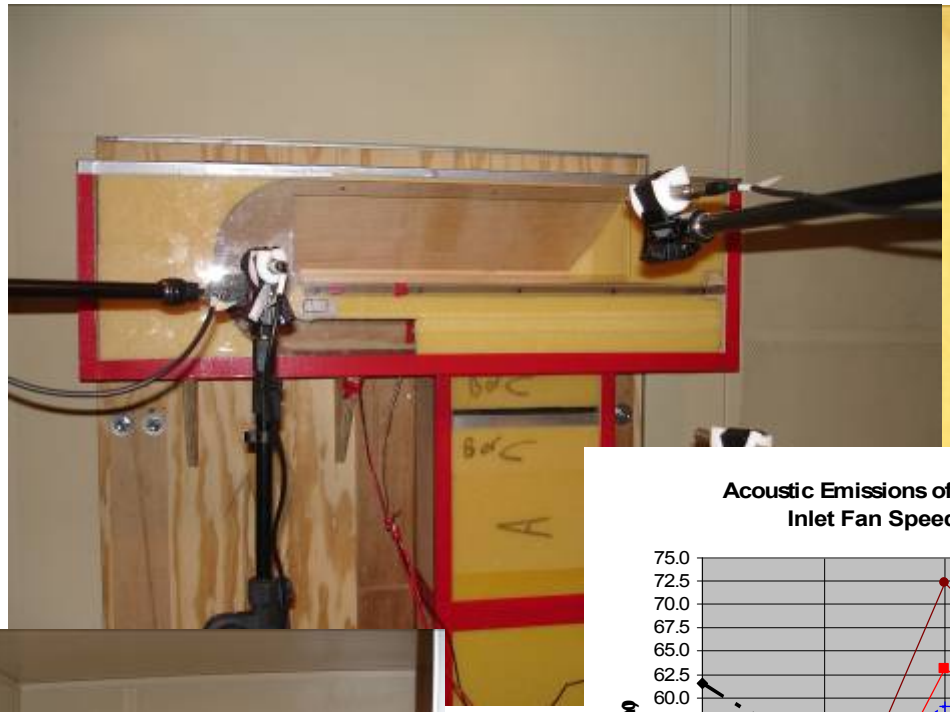
- *Noise allocation and ANCP*
- *Wooden mockuup*
- *Fan selection*
- *Blanket design*
- *Mid-fidelity mockup*
- *Ground verification*
- *Resonance and fan speed control*
- *On-orbit levels*





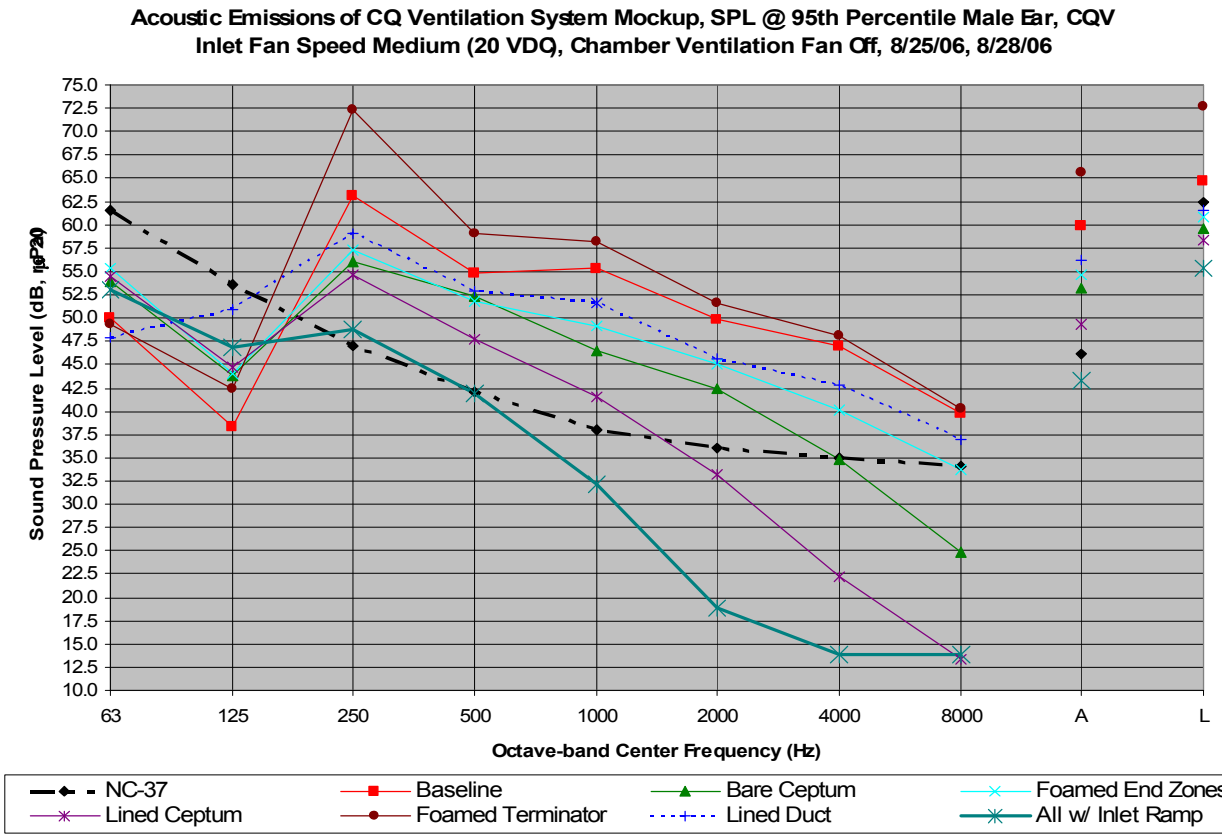
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CQ Ventilation System Wooden Mockup





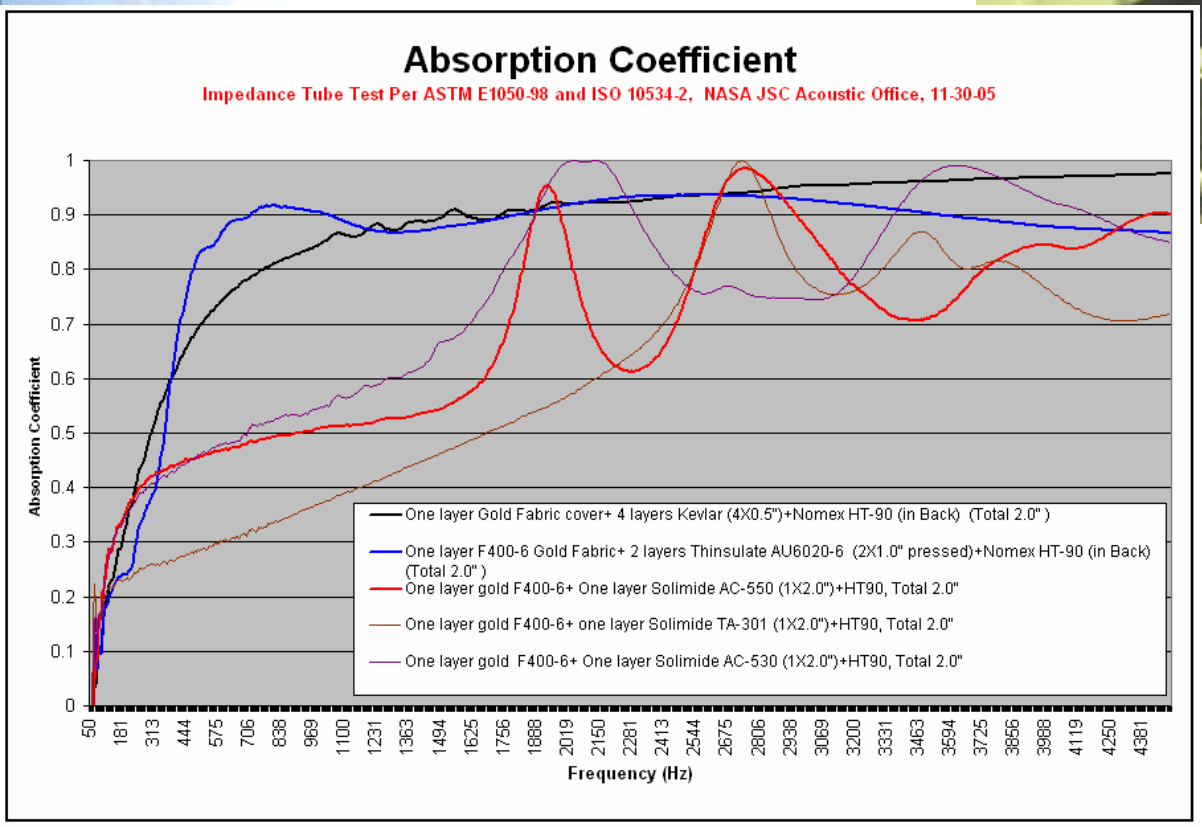




Materials Development (Absorption)

- Need to replace Melamine
- Need covering to contain particulates
- Assess layups
- Used new materials in CQ
  - duct-borne noise absorption
  - interior absorption



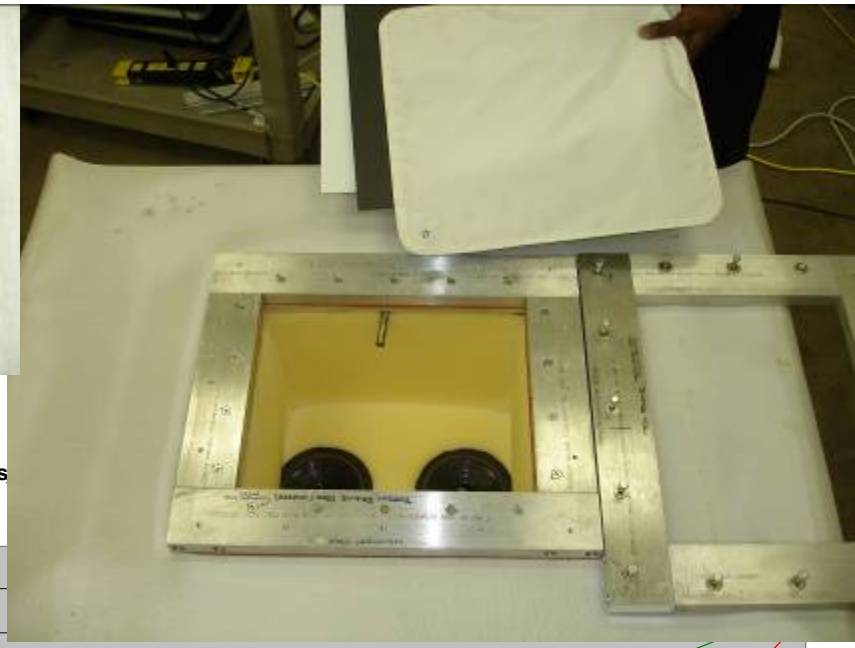


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Materials Development (Transmission Loss)

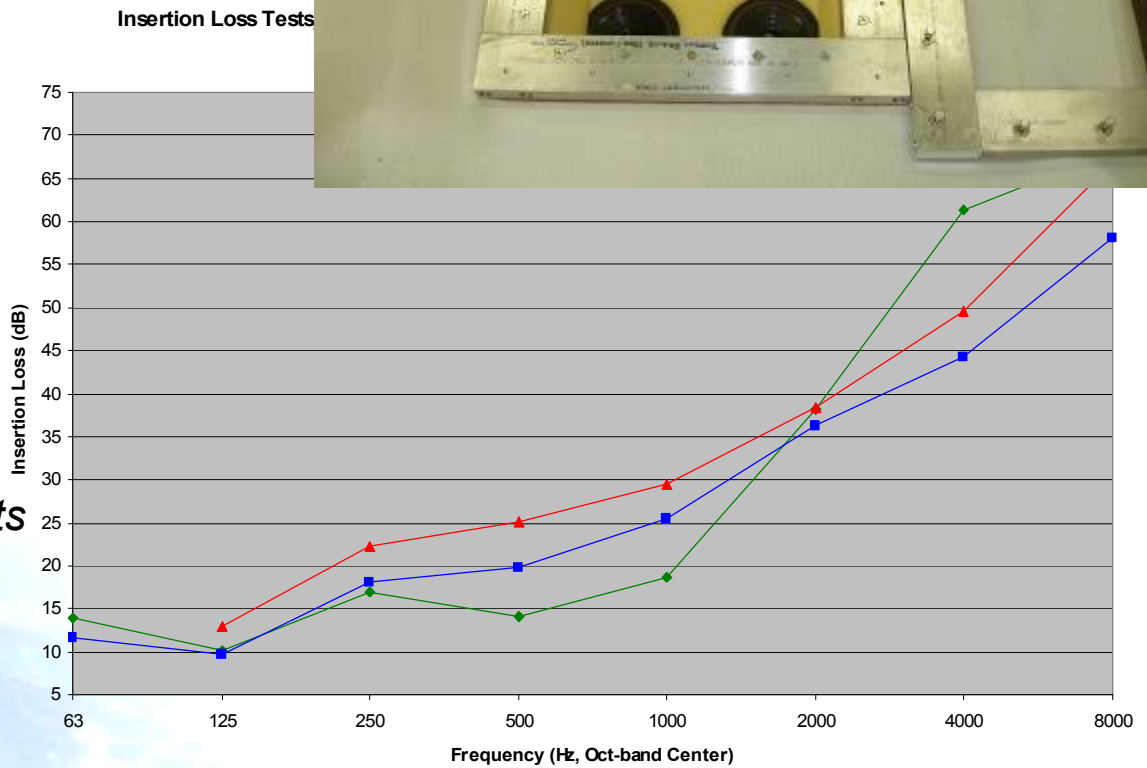




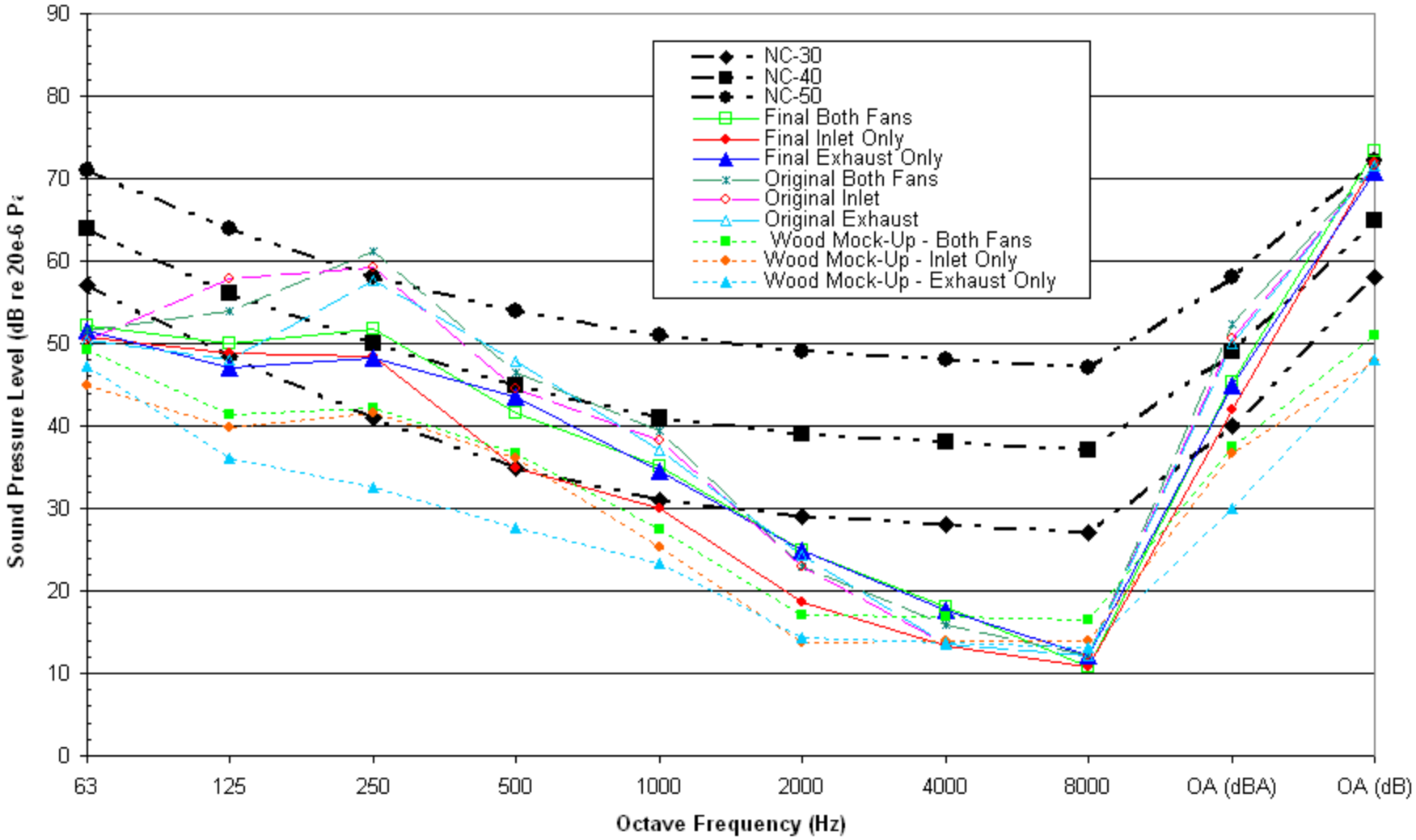




- *Test to determine blocking benefits*
- *BISCO, Radiation Panels, Closeouts*
- *Used in CQ development*



Comparison of Engineering Mock-up, Initial Mid-Fidelity Mock-up, and Final Mid Fidelity Mock-up Levels Ventilation at Low Speed



Overview: Inlet Blade Pass Frequency

- *Problem:*
  - ***Intake fan blade pass frequency (BPF) remains the primary acoustic exeedance root cause.***
    - *Same issue as with the Mid Fidelity Mockup before decoupling and moving the inlet fan.*
    - *The levels of the intake fan BPF are over 10 dB greater than any other narrow-band signal in the vicinity of the 250 Hz octave for the low and medium speed ventilation modes.*
  - ***This was also the case with the mid-fidelity mock-up, however the levels were significantly reduced due to inlet fan decoupling measures (which were integrated into the flight design).***
- *Flight Unit vs. Mid-Fidelity Mockup*
  - ***Significant difference between the mid-fidelity unit and the flight unit is the fan speed and resulting BPF at low speed ventilation.***

	Flight - Low	Mid-Fidelity - Low	Flight - Med	Mid-Fidelity - Med	Flight - High	Mid-Fidelity - High
Intake Fan Rotation Speed (Hz)	40	44	54	56	64	64
Intake Fan BPF (Hz)	201	220	268	281	320	322
Exhaust Fan Rotation Speed (Hz)	47	48	59	60	69	68
Exhaust Fan BPF (Hz)	233	238	296	300	344	340

- *Conclusion:* ***Assuming that the interior dimensional differences between the flight unit and the mid-fidelity unit are minimal, then the difference in frequency of the BPF coupled with the acoustical characteristics of the interior could be the source of the increase in levels of the 250 Hz octave (and also the solution for reducing the flight unit levels).***

Method of Analysis

It is important to characterize both the** source **(intake fan BPF), and the** path **(structural and airborne paths to occupant), in order to understand the sound levels at the receiver (occupant ear location).

Source

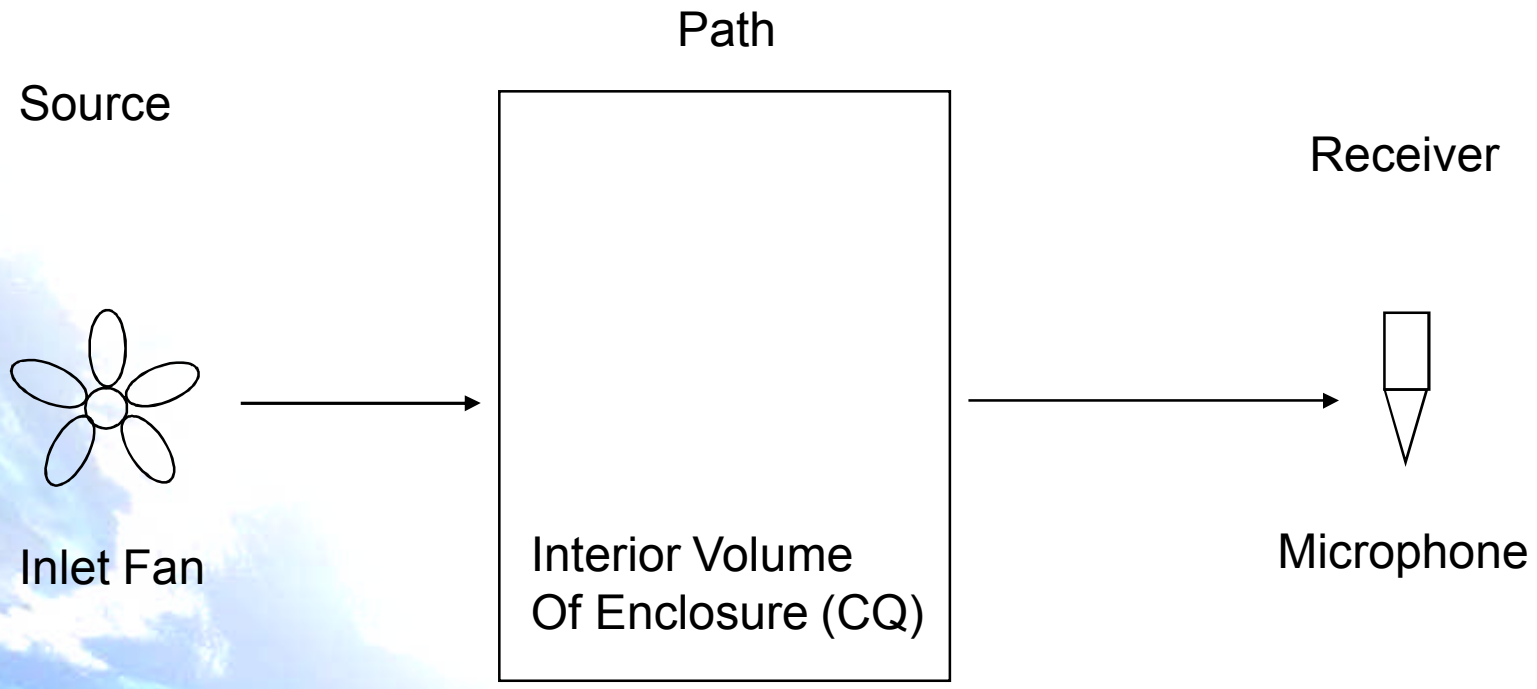
- ***The narrow band measurement of the interior levels in the vicinity of the 250 Hz octave were analyzed.***
  - ***The blade pass frequencies of the intake and exhaust fans are recorded as well as the other rotation orders of the fans.***

(Airborne) Path

- ***The interaction of the crew quarters interior volume is examined by measurement of the acoustical transfer function between the diffuser and the occupant head location.***
  - ***The transfer function acts as an "amplifier" (multiplier) between the intake fan BPF (source) and the occupant ear (receiver).***

A comparison of the flight unit intake BPF and the mid-fidelity BPF and their interaction with the room response of the crew quarters interior volume is made in order to understand the difference in acoustic performance.

Source – Path – Receiver Acoustical Model

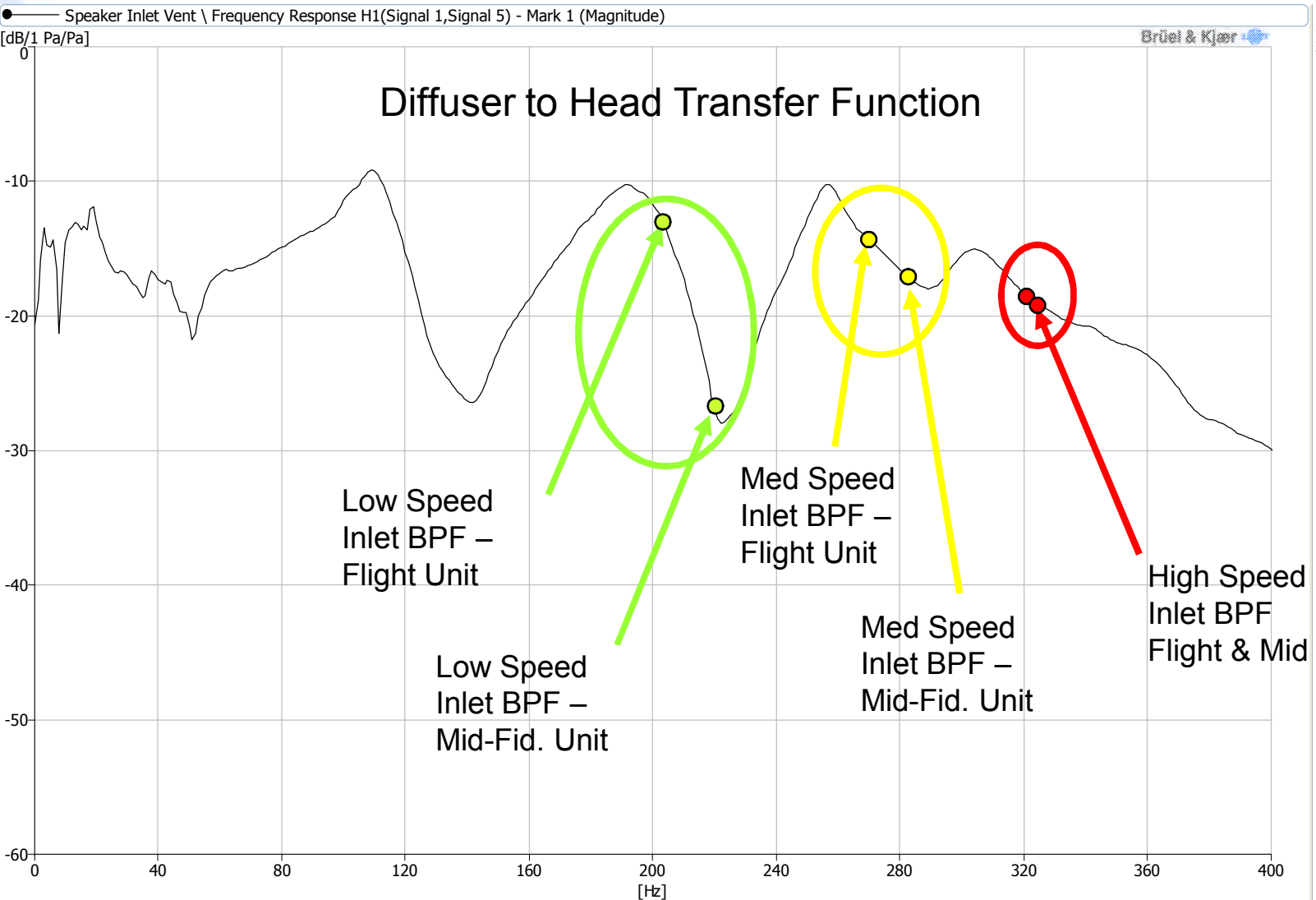


Narrow Band Spectrum

Transfer Function
(Frequency Response Function)

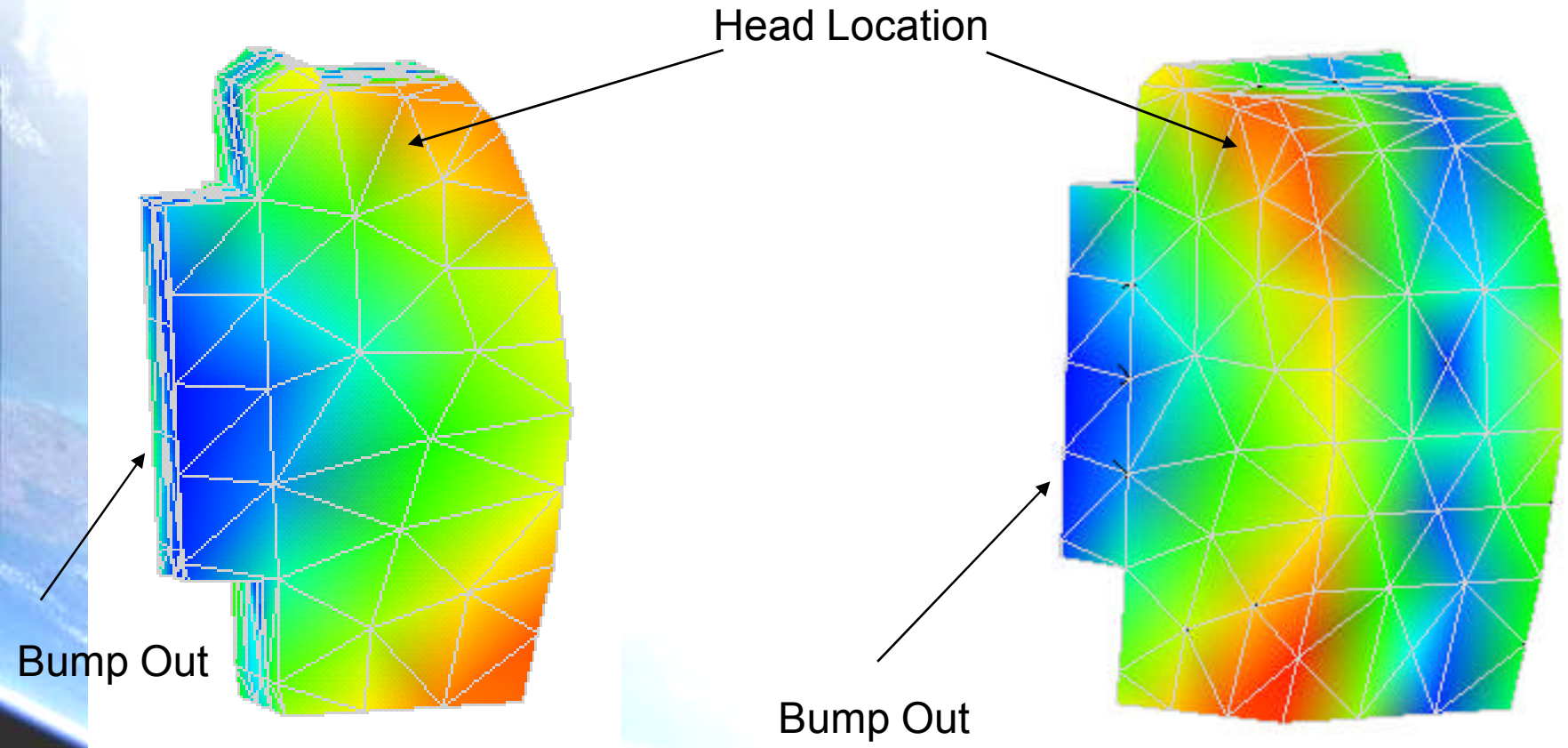
Measured
Response

Intake Measured Transfer Function to Occupant Head Location



CQ Interior Volume Acoustic Mode

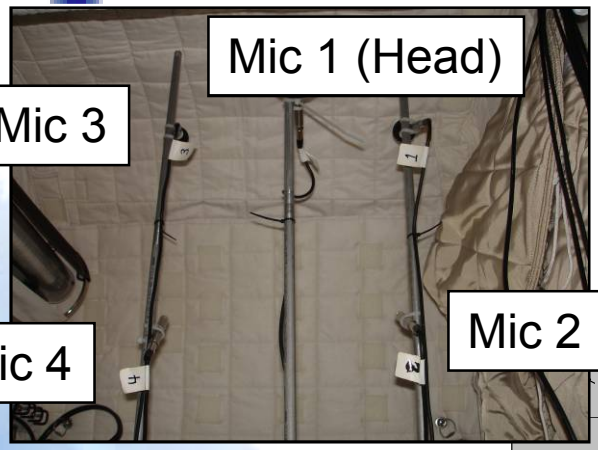
Acoustic Finite Element Modal Analysis of CQ Interior Cavity
Mode Frequency: 194 Hz

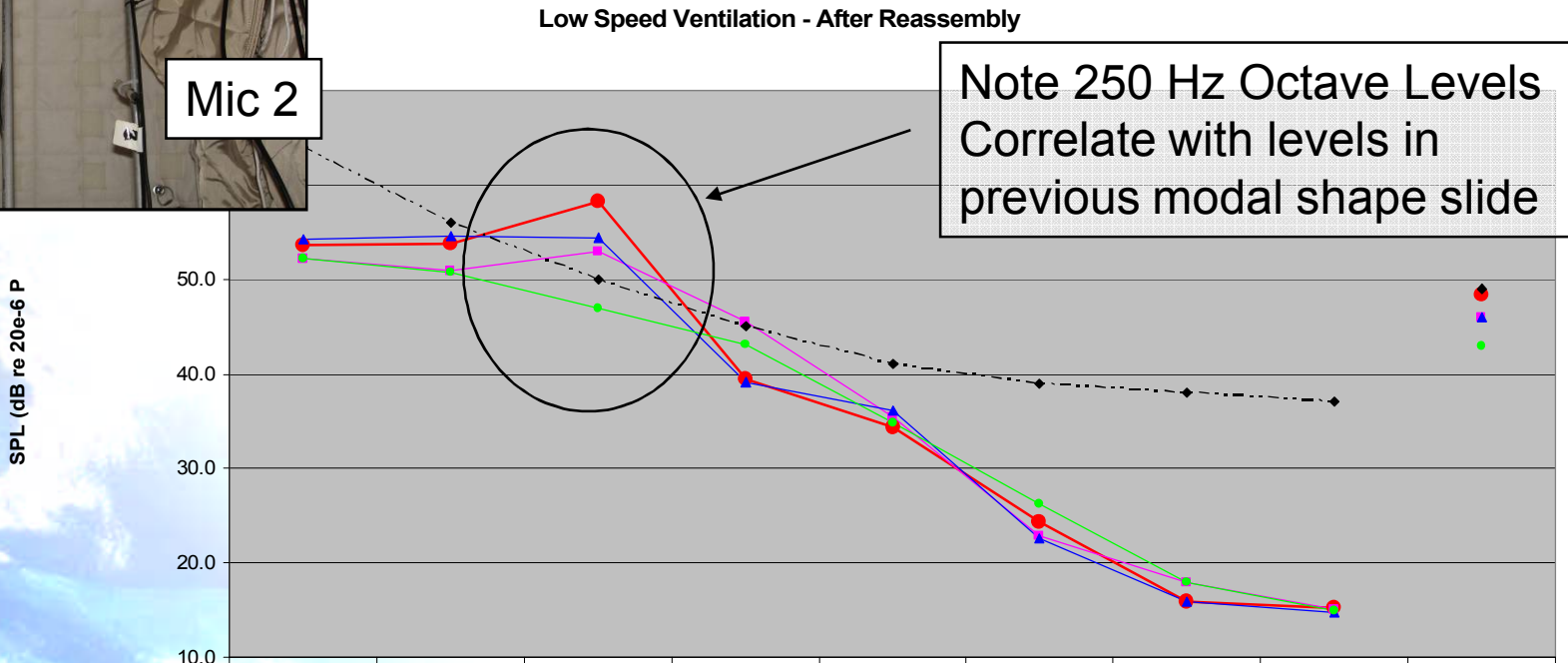


What this Means: SPL due to blade pass frequency at 201 Hz should decrease as the measurement location moves towards the center of the CQ interior volume (see next slide).

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Variation of Octave Levels with Location in CQ Volume





Note 250 Hz Octave Levels Correlate with levels in previous modal shape slide

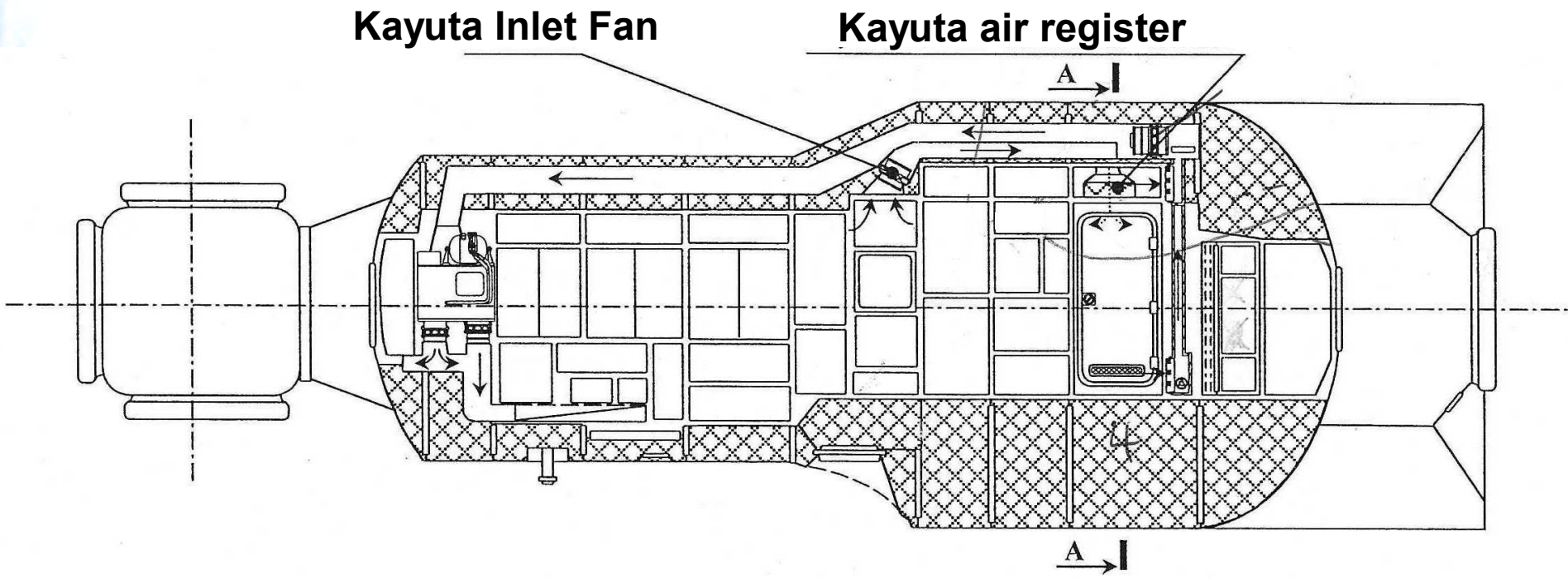
	63	125	250	500	1000	2000	4000	8000	A column:
Mic 1 (Head)	53.6	53.8	58.2	39.4	34.3	24.4	15.8	15.2	48.4
Mic 2	52.1	50.9	52.9	45.5	35.5	23.0	18.0	15.1	45.9
Mic 3	54.3	54.6	54.4	39.1	36.0	22.6	15.9	14.8	45.9
Mic 4	52.2	50.8	47.0	43.2	34.9	26.2	18.0	14.9	43.0
NC-40	64	56	50	45	41	39	38	37	49

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Backup

Profile Cross-Section of Service Module



Kayuta Acoustic Treatments





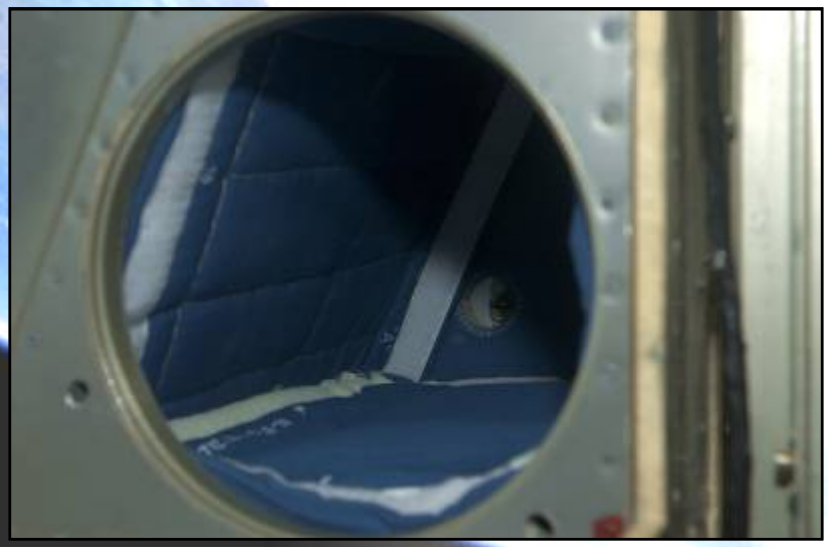


Ventilation Subsystem

Installation of mufflers and shock absorbers on BB1PO







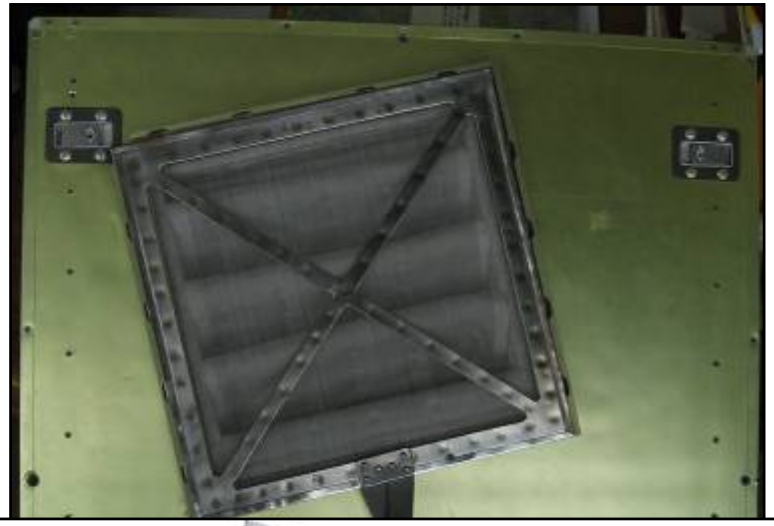


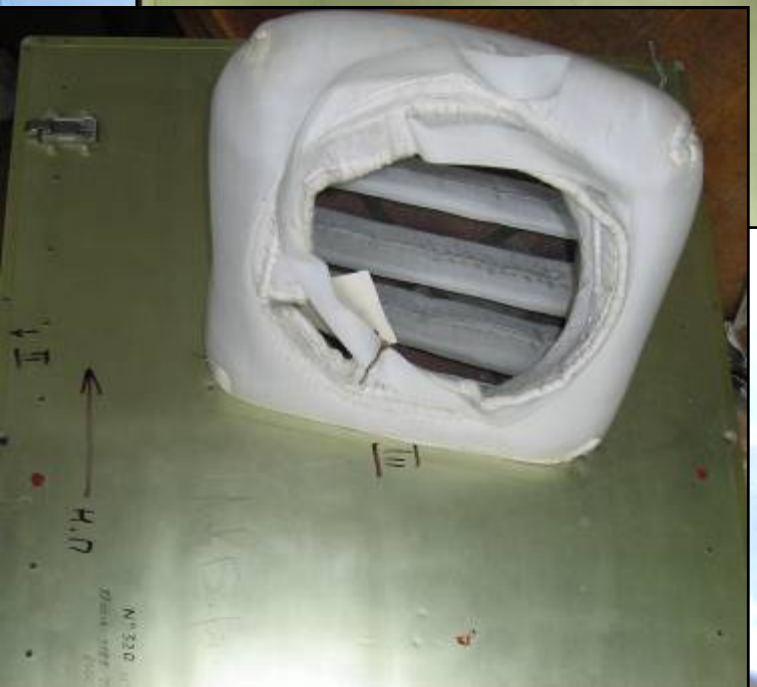
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Ventilation Subsystem

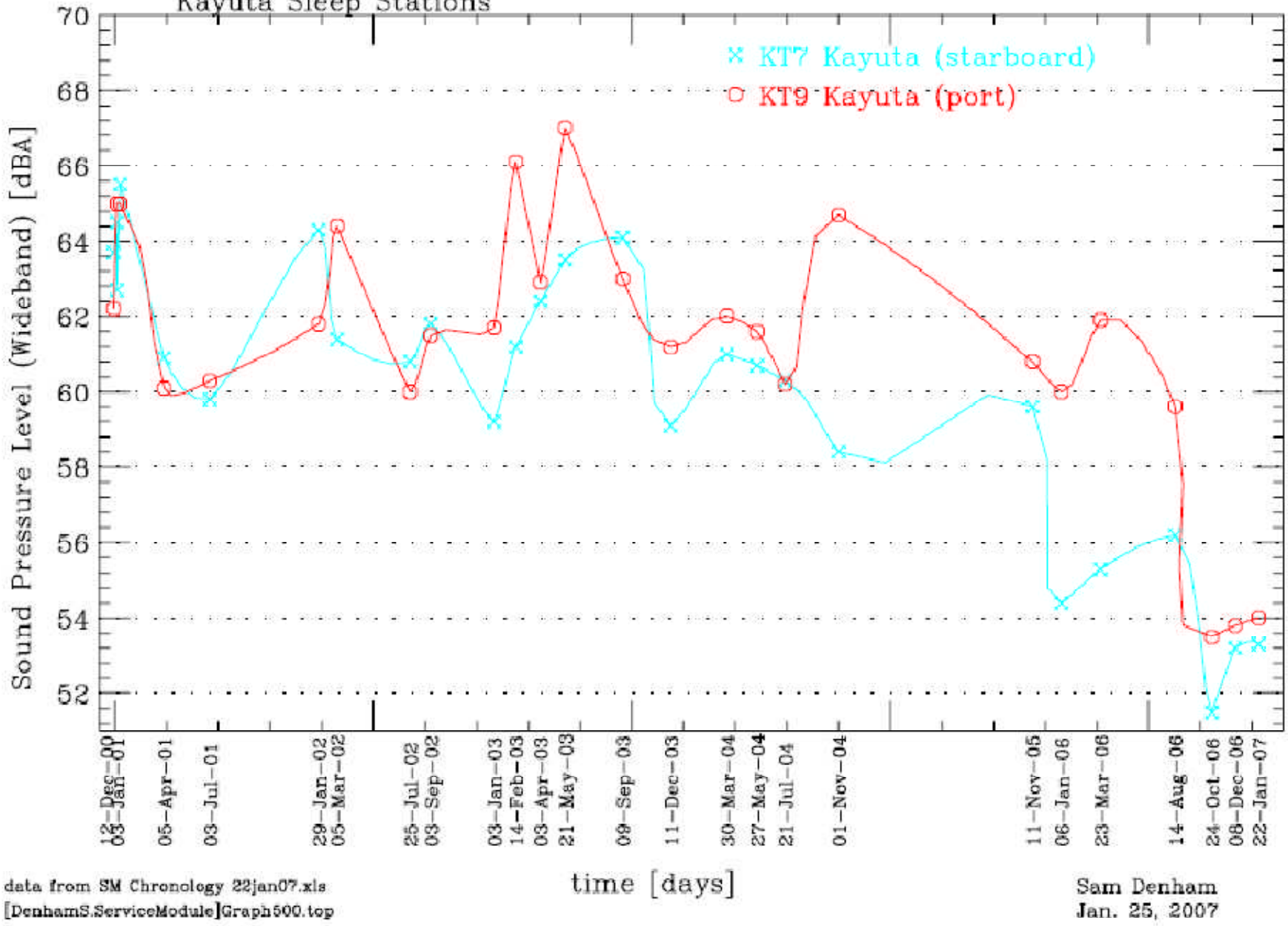
Installation of acoustic screens and soft air ducts on fans ВКЮ1 (ВКЮ2)





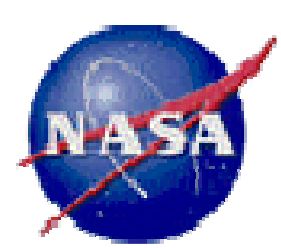






data from SM Chronology 22jan07.xls
[DenhamS.ServiceModule]Graph500.top

Sam Denham
Jan. 25, 2007



Vozdukh System

Vozdukh System

Results of installing soundproof cover on БОА fan onboard the ISS SM





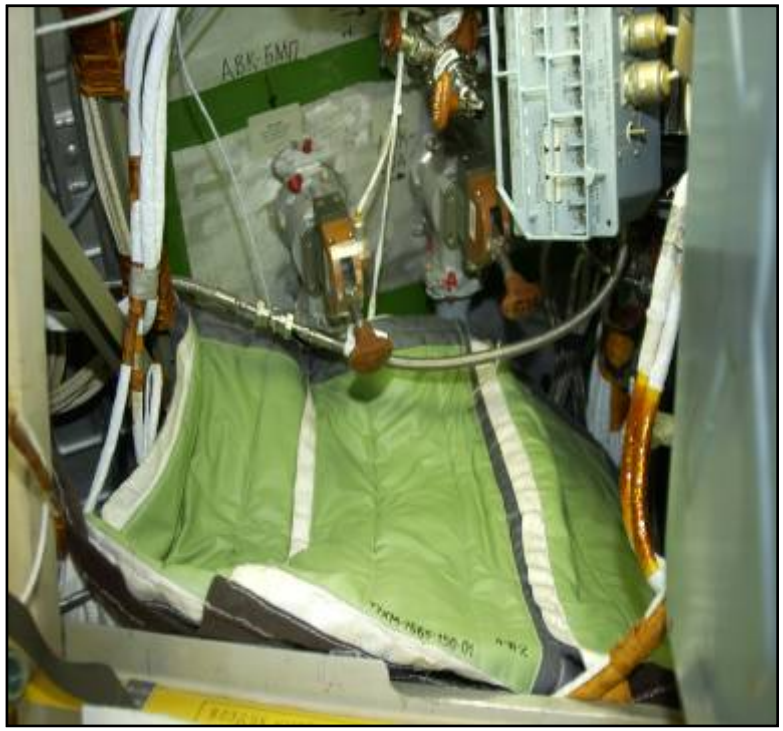
- ***Complete installation of cover on board the ISS SM unsuccessful***
- ***Space between vacuum pipeline and bar near fan insufficient to install the upper half of the cover.***

Vozdukh System

Results of installing soundproof cover on БОА fan

- ***Adapter, shock absorber, and soft soundproof cover installed***



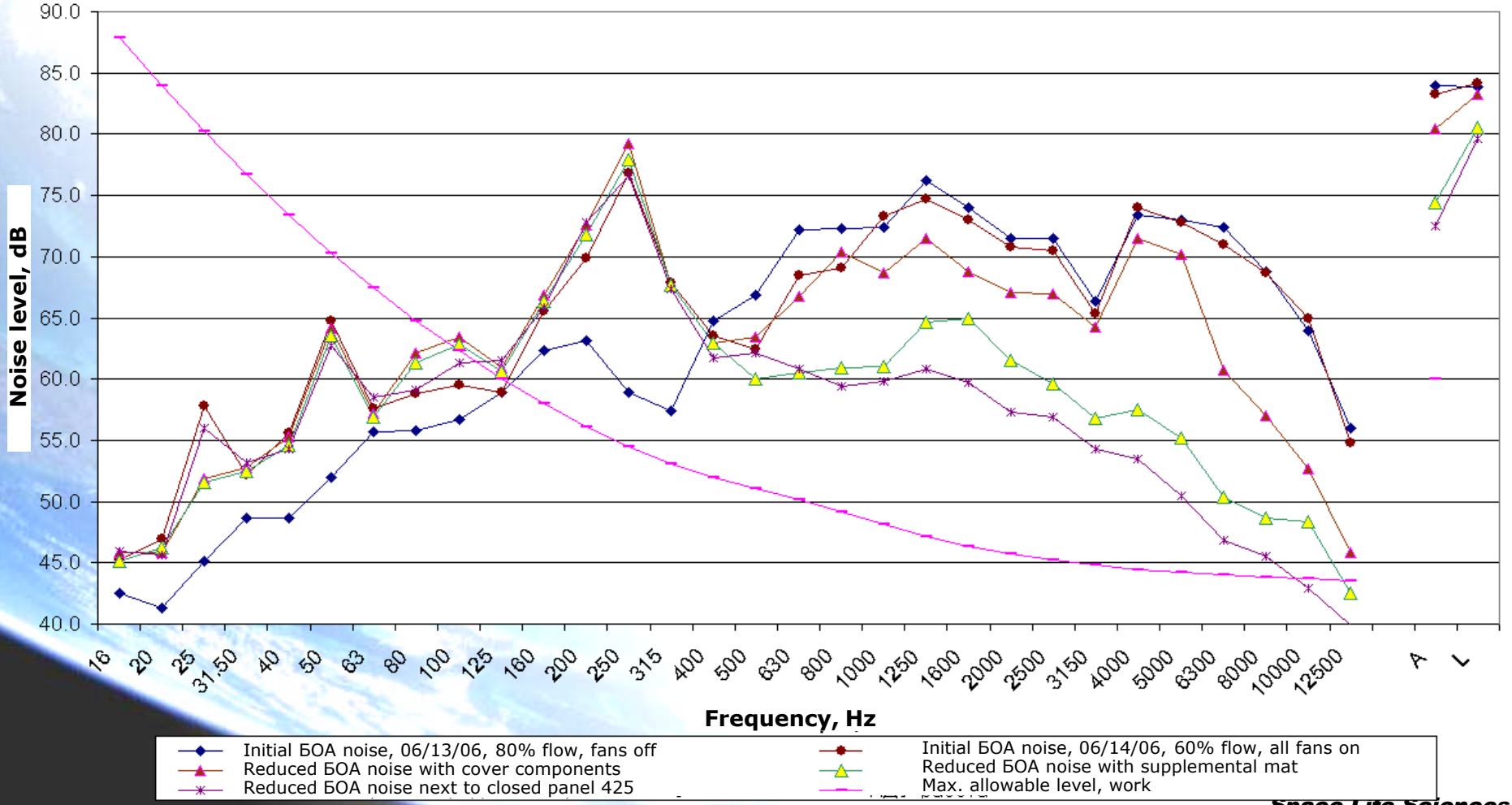


- ***Upon crew initiative, additional soundproofing device installed for БОА unit components behind panel 425***

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Vozdukh System Microcompressor Noise 13–14 June 2006

Noise 50 cm from БОА fan before and after installation of cover 4315 and mats

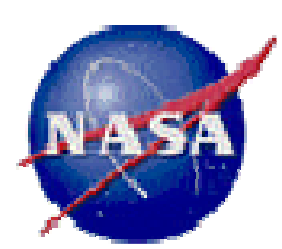


Vozdukh System

Results of installing soundproof cover on БОА fan

Findings:

- ***In the SM, noise from БОА was reduced by ≈ 9 dBA***
- ***Installation of metal box was not possible***
- ***Noise level reduction value obtained is close to that measured during ground tests with the box (≈ 11 dBA)***



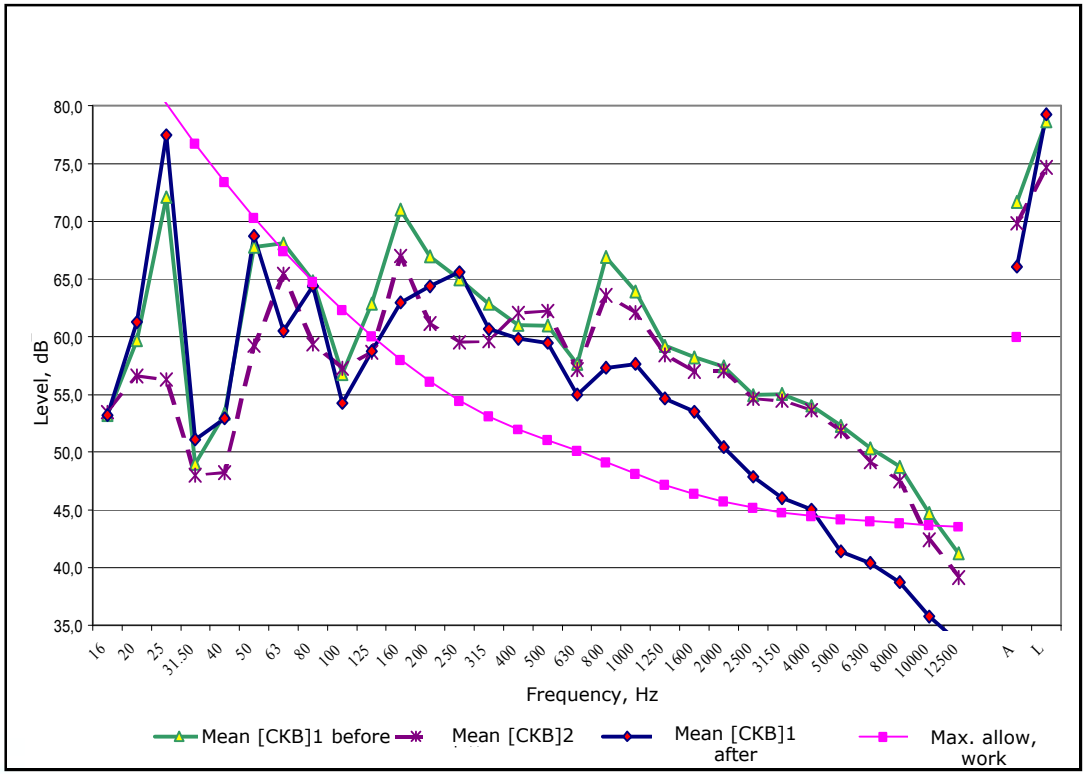
Air Conditioning System [CKB]

CKB Modifications



Integrated interior panel 204+205 installed on board the ISS RS SM

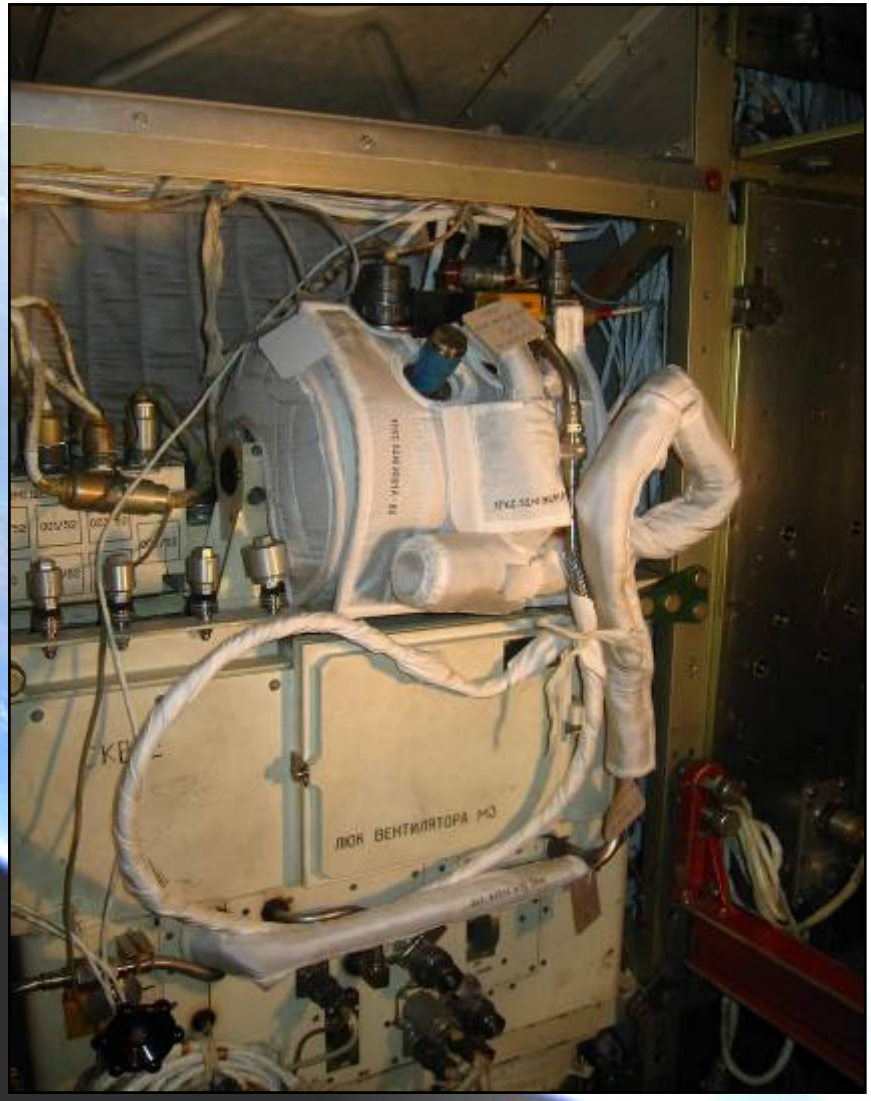
Noise spectra in zone of [CKB]1 before and after the installation of soundproofing panel 204+205



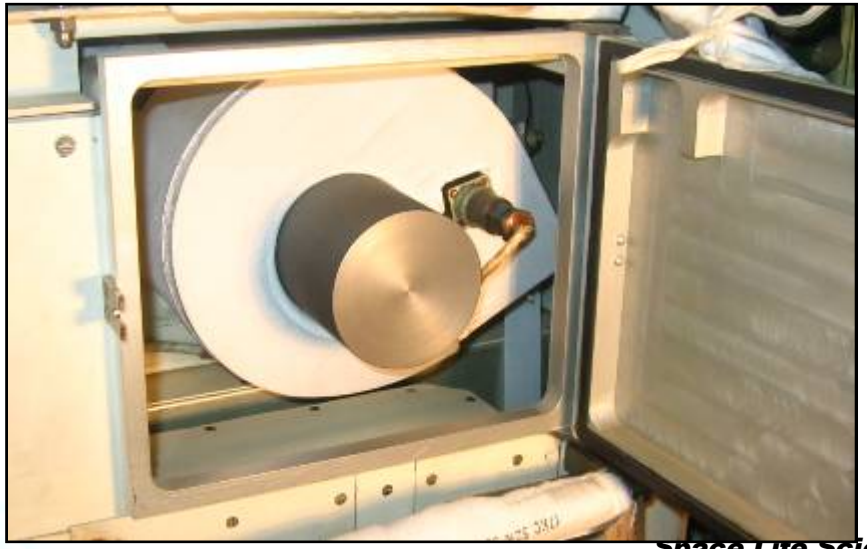
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Air Conditioning System [СКВ]

Soundproofing devices 17КС.52Ю 9081А-0



- For [СКВ]2 – all soundproofing items installed on 07/19/06
- For [СКВ]1 – only the cover on [ВР] was installed; all else planned for installation before БТА changeout in June 2007.



Air Conditioning System [CKB]

Results of installing noise-reduction devices for the [CKB]

Findings:

- ***Due to installation of integrated panel 204+205, noise level near [CKB] fell by at least 5 dBA (to 65.8 – 66.3 dBA)***
- ***Due to installation of soundproofing devices on [CKB]2, vibration isolation for [BT]2 and a shock absorber for [BTK]2 (per noise measurement data on 07/19/06), the following noise levels were achieved:***
  - ***≈ 64.5 dBA - near central post***
  - ***≈ 66 dBA - near Vozdukh system***
  - ***≈ 68.5 dBA - near [CKB] (point [KT]2)***
- ***In August 2006, an unexplained increase in noise occurred near [CKB]2, up to 71-73 dBA (this made it difficult to determine the effectiveness of installing the shock absorber for fan [BTK]1 of [CKB]1)***